MEG as an Enabling Tool in Neuroscience – Transcending Boundaries with New Analysis Methods and Devices

Matti Hämäläinen

Athinoula A.
Martinos Center
For Biomedical Imaging

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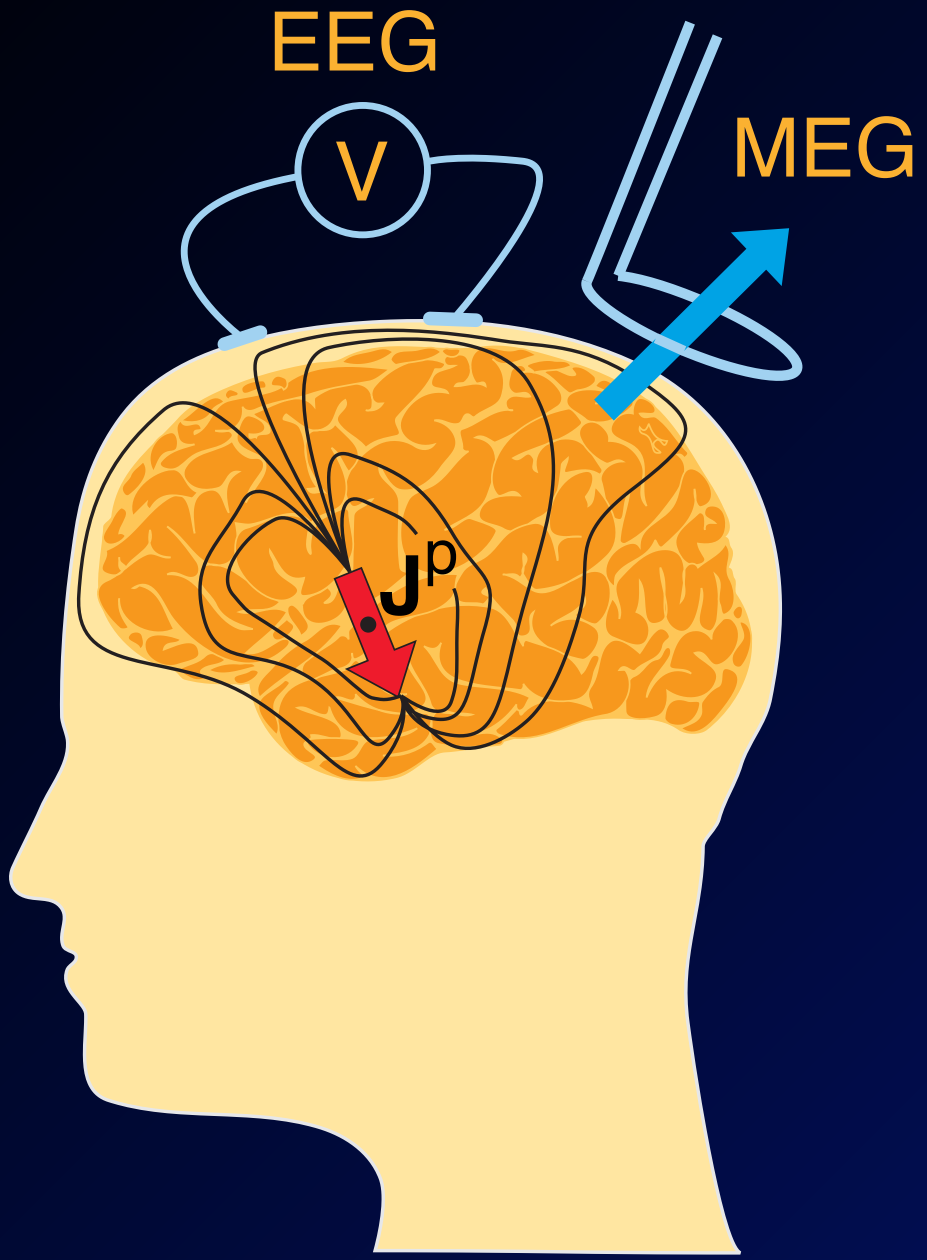
Brain Imaging and Neuroscience

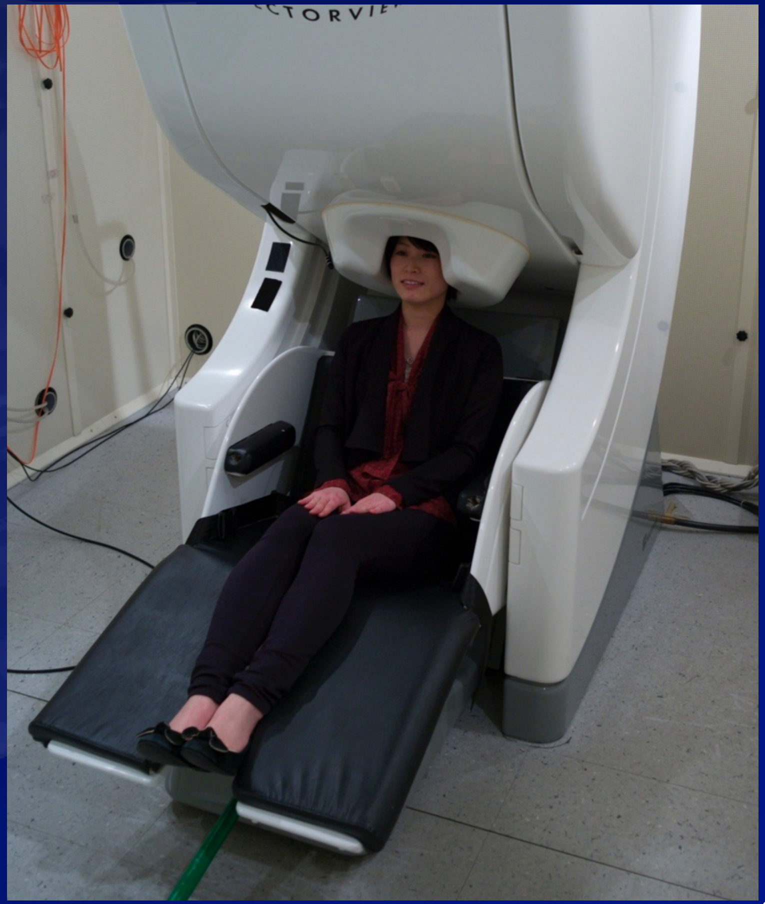
I keep six honest serving men
(They taught me all I knew);
Their names are What and Why and When
And How and Where and Who.

Rudyard Kipling

Who and When and How: MEG and EEG



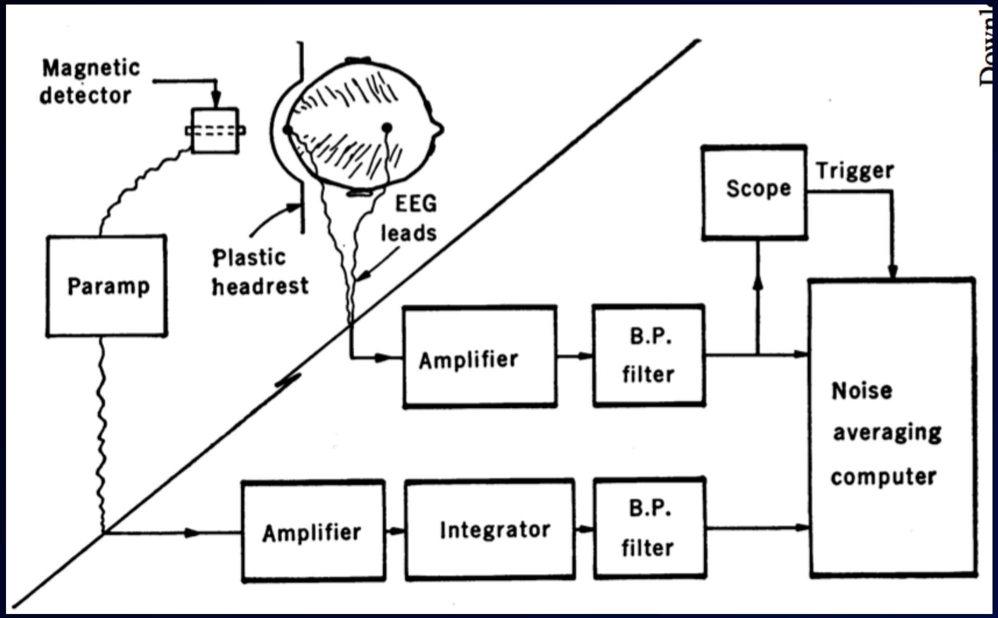
- Measure the electric potential (EEG) magnetic field (MEG) generated by neural currents
- Who: Reasonable spatial resolution
- When: Real-time measures of brain activity
- How: Frequency-specific connectivity

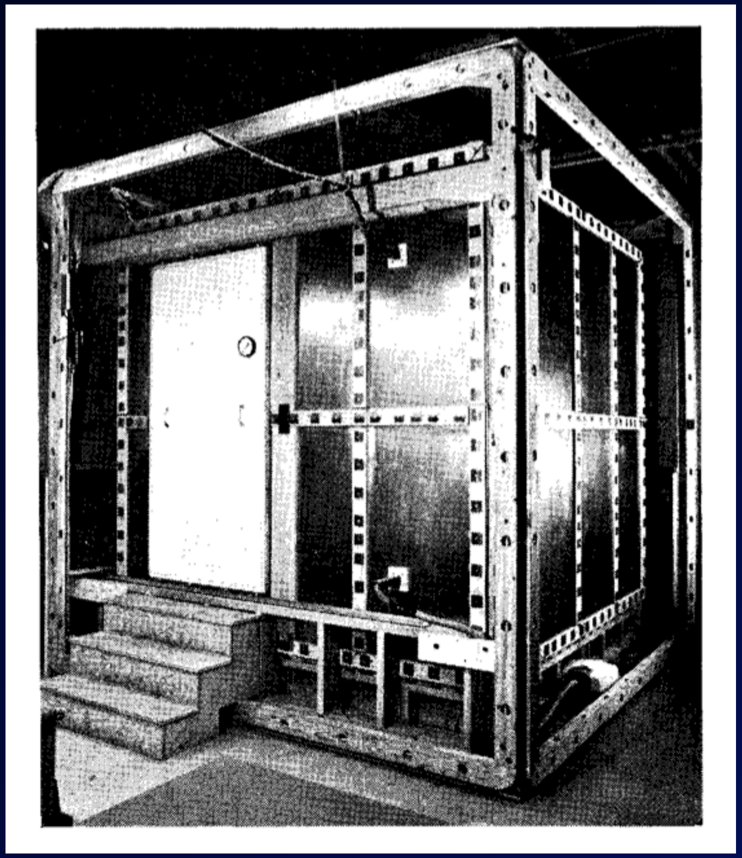


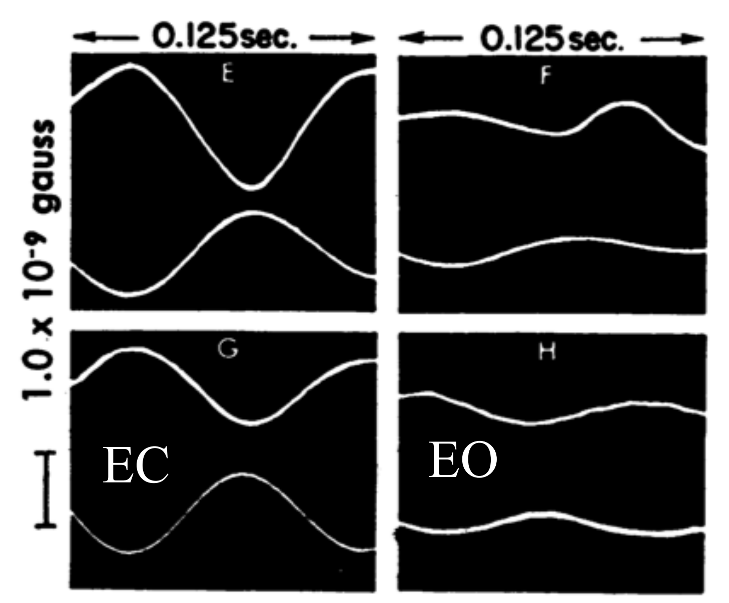
Contents

- Humble beginnings
- From one to hundreds of channels
- Insights from the Maxwell’s equations
- Moving to source space
- Are the new sensor technologies a breakthrough?

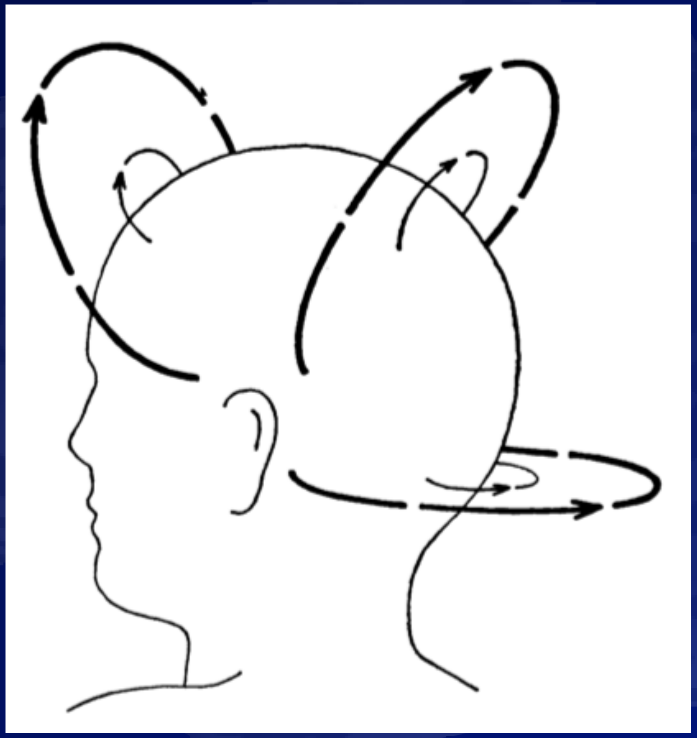
First MEG with EEG reference





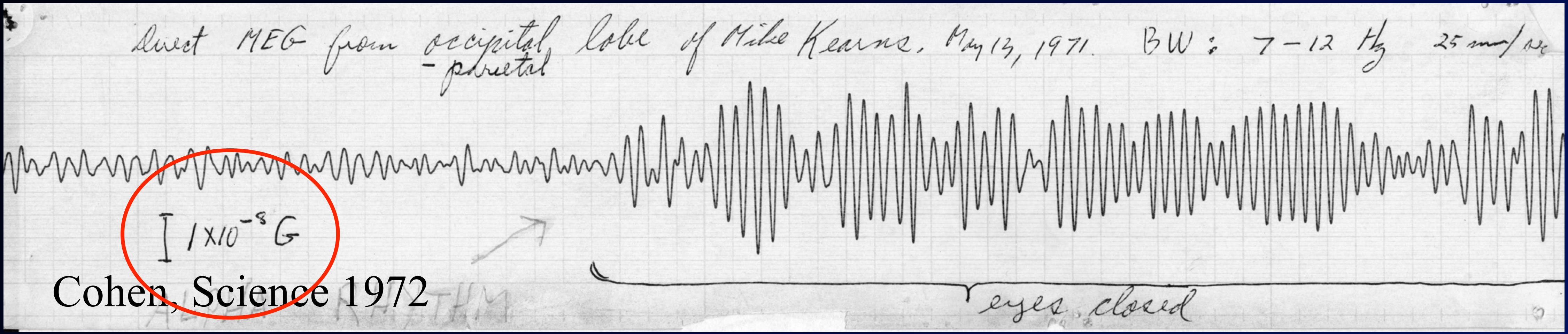


N = 2500

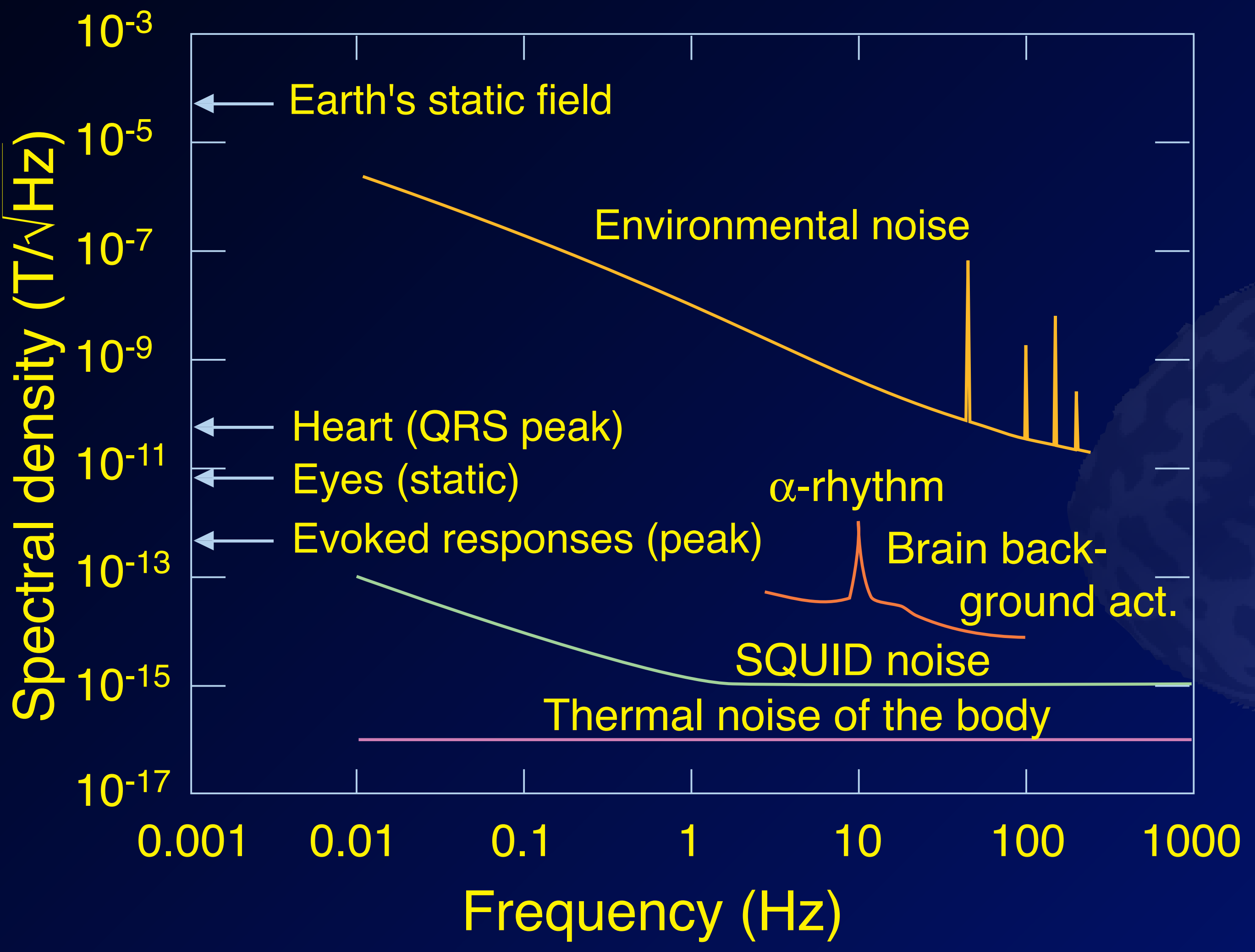


Cohen D, J. Appl. Phys, 1967; Science, 1968

First Real-Time Magnetoencephalogram



Cohen, Science 1972



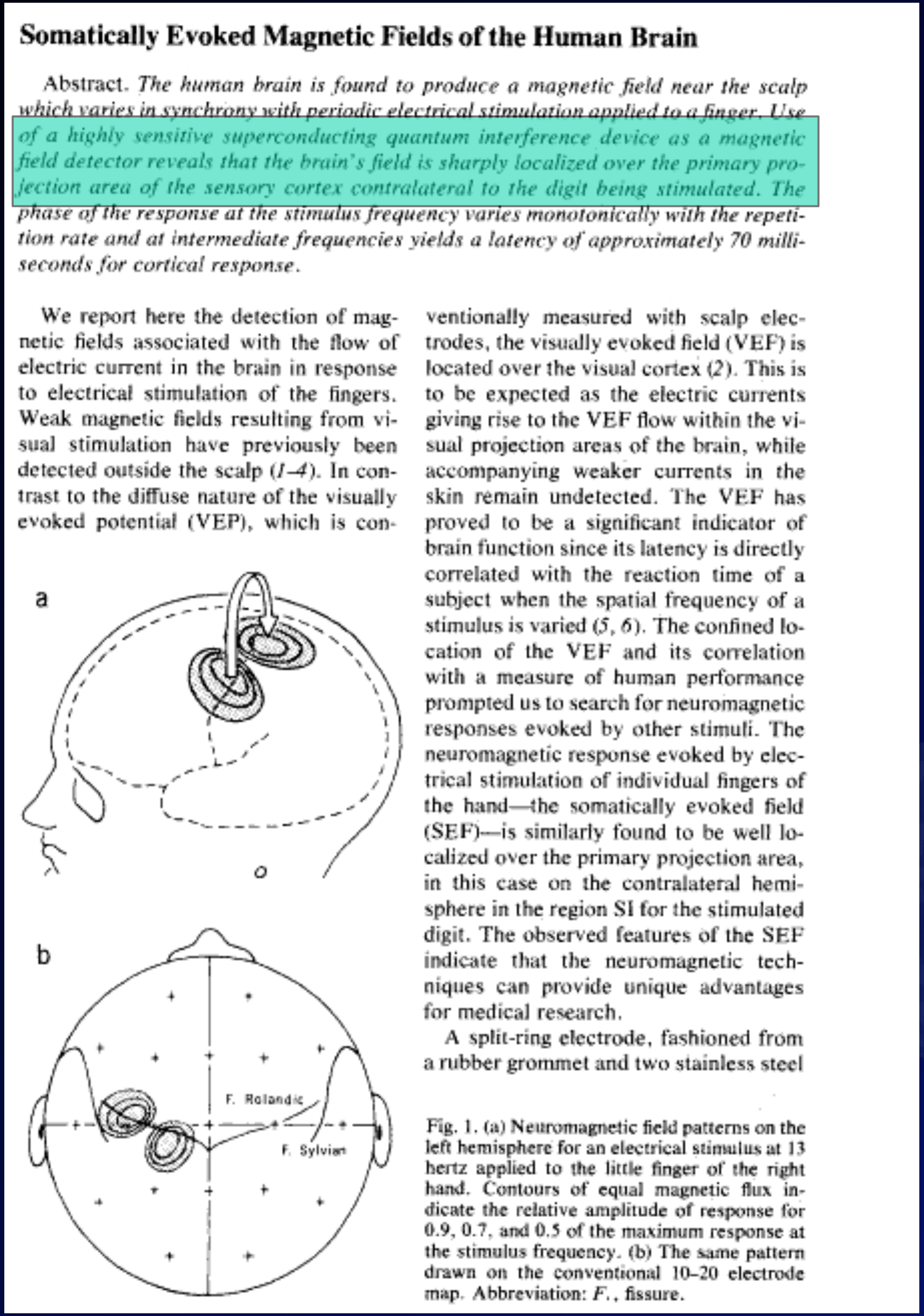
I believe the high-sensitivity detection system used here shows promise both as a clinical and as a research tool for studying the brain.

Cohen, Science, 1972

Sam Williamson † and Lloyd Kaufman (NYU):

- First VEF and mapping of somatosensory fields
- Interdisciplinary approach
- Magnetic Source Imaging (MSI)

Dipolar field pattern: Focal sources



Somatically Evoked Magnetic Fields of the Human Brain

Abstract. *The human brain is found to produce a magnetic field near the scalp which varies in synchrony with periodic electrical stimulation applied to a finger. Use of a highly sensitive superconducting quantum interference device as a magnetic field detector reveals that the brain's field is sharply localized over the primary projection area of the sensory cortex contralateral to the digit being stimulated. The phase of the response at the stimulus frequency varies monotonically with the repetition rate and at intermediate frequencies yields a latency of approximately 70 milliseconds for cortical response.*

We report here the detection of magnetic fields associated with the flow of electric current in the brain in response to electrical stimulation of the fingers. Weak magnetic fields resulting from visual stimulation have previously been detected outside the scalp (*1–4*). In contrast to the diffuse nature of the visually evoked potential (VEP), which is conventionally measured with scalp electrodes, the visually evoked field (VEF) is located over the visual cortex (*2*). This is to be expected as the electric currents giving rise to the VEF flow within the visual projection areas of the brain, while accompanying weaker currents in the skin remain undetected. The VEF has proved to be a significant indicator of brain function since its latency is directly correlated with the reaction time of a subject when the spatial frequency of a stimulus is varied (*5, 6*). The confined location of the VEF and its correlation with a measure of human performance prompted us to search for neuromagnetic responses evoked by other stimuli. The neuromagnetic response evoked by electrical stimulation of individual fingers of the hand—the somatically evoked field (SEF)—is similarly found to be well localized over the primary projection area, in this case on the contralateral hemisphere in the region SI for the stimulated digit. The observed features of the SEF indicate that the neuromagnetic techniques can provide unique advantages for medical research.

A split-ring electrode, fashioned from a rubber grommet and two stainless steel

Fig. 1. (a) Neuromagnetic field patterns on the left hemisphere for an electrical stimulus at 13 hertz applied to the little finger of the right hand. Contours of equal magnetic flux indicate the relative amplitude of response for 0.9, 0.7, and 0.5 of the maximum response at the stimulus frequency. (b) The same pattern drawn on the conventional 10–20 electrode map. Abbreviation: *F.*, fissure.

Dipolar field patterns observed in several primary MEG responses: a current dipole seemed to be a reasonable model

D. Brenner, J. Lipton, L. Kaufman, S.J. Williamson, Science, 1977

Lloyd Kaufman and David Cohen, October 2017

Soon SQUIDs Arrived to Finland

Pekka Karp and Toivo Katila,
carrying equipment from the wooden
measurement cabin, around 1973

A Vision Can be a Game Changer

We need whole-head MEG and there is no fundamental reason why it could not be built!

Olli V. Lounasmaa
Low Temperature Laboratory
Helsinki University of Technology
Finland

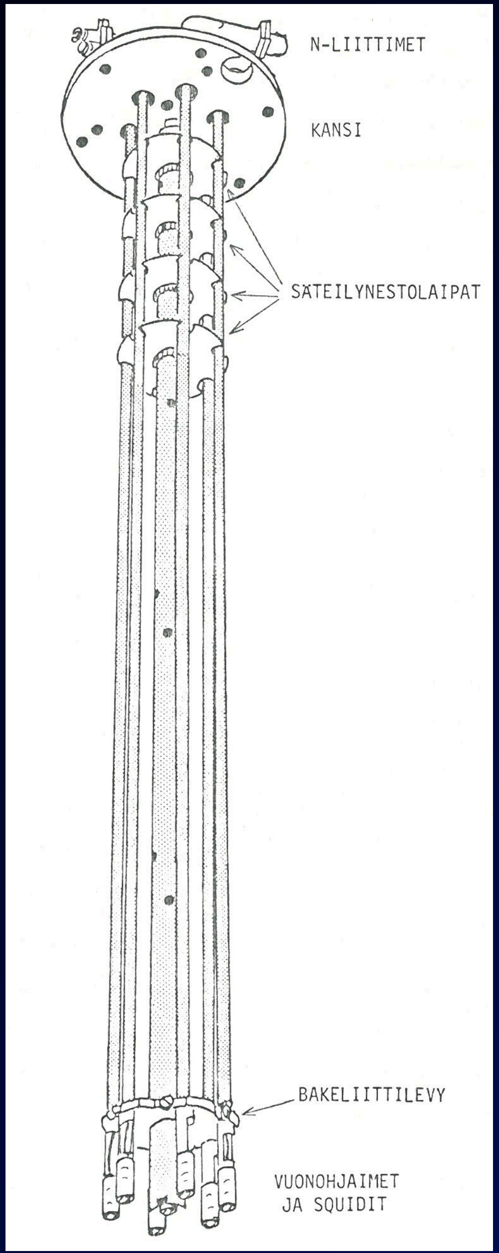
We will establish a multidisciplinary team with full-time neuroscientists

Riitta Hari, hired 1982

MEG is not a hobby!

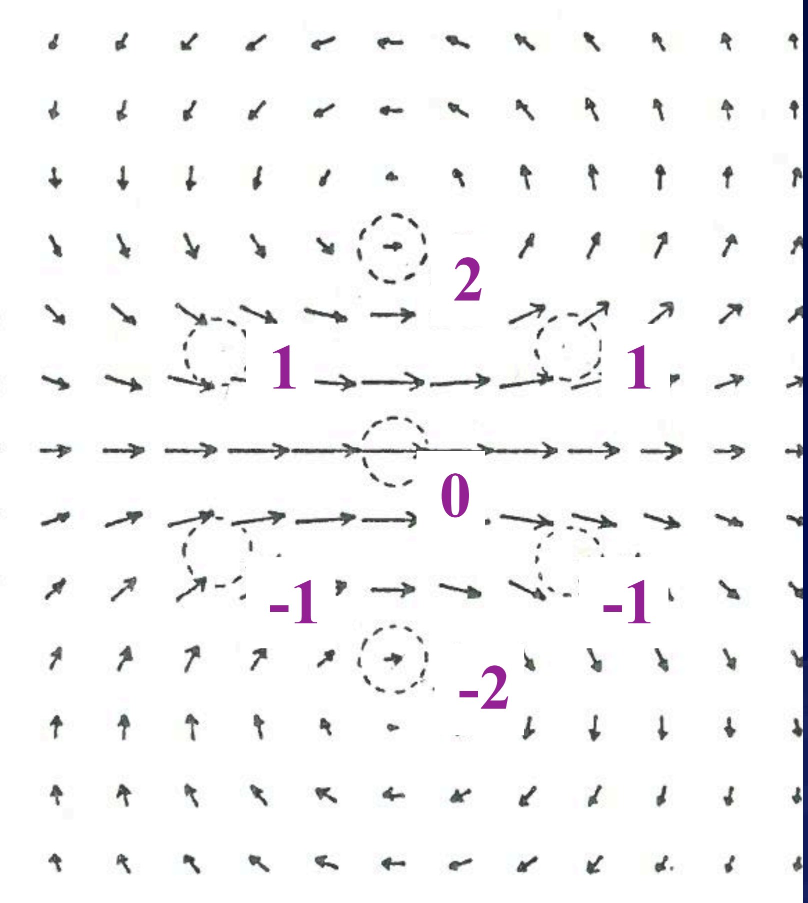
An Early 7-Channel MEG Device

Instrument



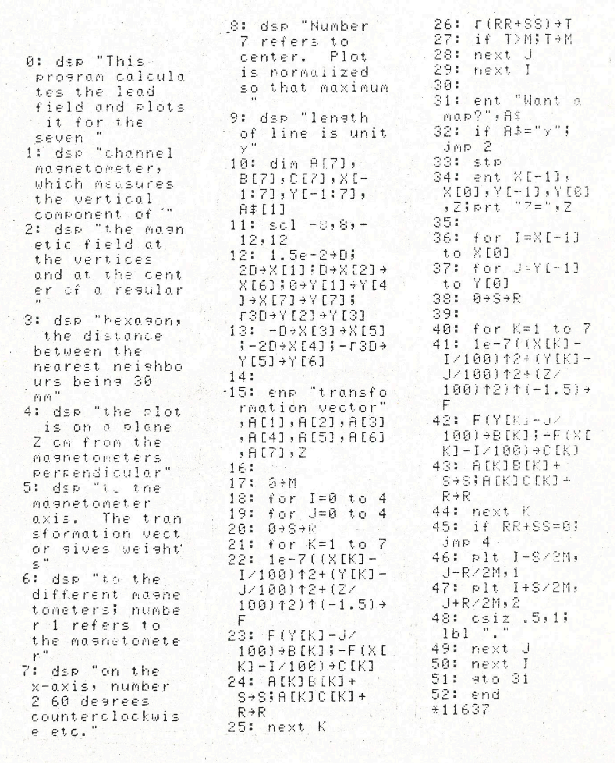
- 7-channel magnetometer
- rf-SQUIDs, flux guides
- 30-mm distance between channels

Analysis



- Linear combinations of lead fields
- Seed ideas for MNE

Open-Source Software



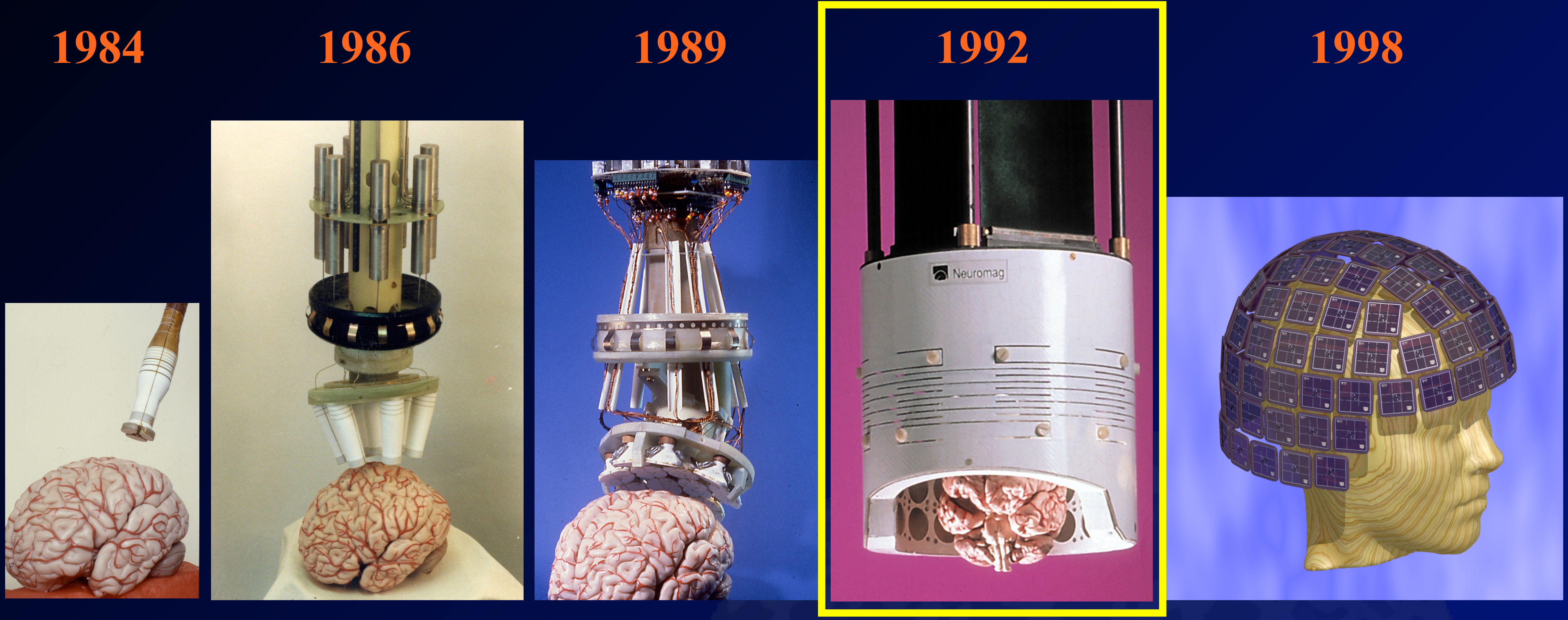
```
0: dsp "This
 program calcula
 tes the lead
 field and plots
  it for the
 seven "
1: dsp "channel
 magnetometer,
 which measures
 the vertical
 component of "
2: dsp "the magn
 etic field at
 the vertices
 and at the cent
 er of a regular
 "
3: dsp "hexagon,
  the distance
 between the
 nearest neighbo
 urs being 30
 mm"
4: dsp "the plot
  is on a plane
 Z cm from the
 magnetometers
 perpendicular"
5: dsp "to the
 magnetometer
 axis.  The tran
 sformation vect
 or gives weight
 s"
6: dsp "to the
 different magne
 tometers; numbe
 r 1 refers to
 the magnetomete
 r"
7: dsp "on the
 x-axis, number
 2 60 degrees
 counterclockwis
 e etc."
8: dsp "Number
 7 refers to
 center.  Plot
 is normalized
 so that maximum
  "
9: dsp "length
 of line is unit
 y"
10: dim A[7],
 B[7],C[7],X[-
 1:7],Y[-1:7],
 A$[1]
11: scl -8,8,-
 12,12
12: 1.5e-2→D;
 2D→X[1];D→X[2]→
 X[6];0→Y[1]→Y[4
 ]→X[7]→Y[7];
 r3D→Y[2]→Y[3]
13: -D→X[3]→X[5]
 ;-2D→X[4];-r3D→
 Y[5]→Y[6]
14:
15: enp "transfo
 rmation vector"
 ,A[1],A[2],A[3]
 ,A[4],A[5],A[6]
 ,A[7],Z
16:
17: 0→M
18: for I=0 to 4
19: for J=0 to 4
20: 0→S→R
21: for K=1 to 7
22: 1e-7((X[K]-
 I/100)↑2+(Y[K]-
 J/100)↑2+(Z/
 100)↑2)↑(-1.5)→
 F
23: F(Y[K]-J/
 100)→B[K];-F(X[
 K]-I/100)→C[K]
24: A[K]B[K]+
 S→S;A[K]C[K]+
 R→R
25: next K
26: r(RR+SS)→T
27: if T>M;T→M
28: next J
29: next I
30:
31: ent "Want a
 map?",A$
32: if A$="y";
 jmp 2
33: stp
34: ent X[-1],
 X[0],Y[-1],Y[0]
 ,Z;prt "Z=",Z
35:
36: for I=X[-1]
 to X[0]
37: for J=Y[-1]
 to Y[0]
38: 0→S→R
39:
40: for K=1 to 7
41: 1e-7((X[K]-
 I/100)↑2+(Y[K]-
 J/100)↑2+(Z/
 100)↑2)↑(-1.5)→
 F
42: F(Y[K]-J/
 100)→B[K];-F(X[
 K]-I/100)→C[K]
43: A[K]B[K]+
 S→S;A[K]C[K]+
 R→R
44: next K
45: if RR+SS=0;
 jmp 4
46: plt I-S/2M,
 J-R/2M,1
47: plt I+S/2M,
 J+R/2M,2
48: csiz .5,1;
 lbl "."
49: next J
50: next I
51: gto 31
52: end
*11637
```

- Software on an HP 9825 desk calculator

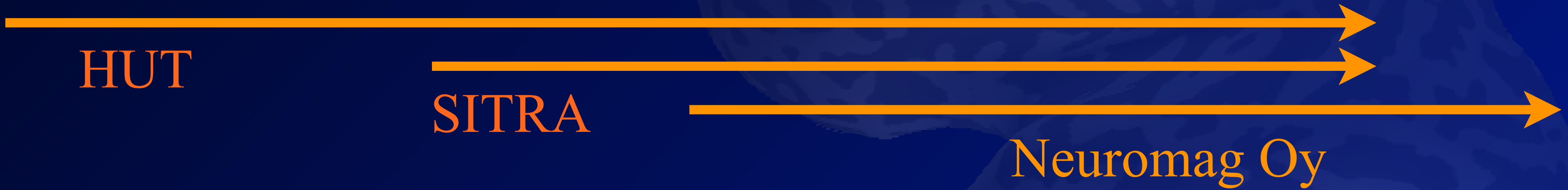
Ehnholm GJ, Ilmoniemi RJ, and Wiik TO, Physica B+C, 107: 29-30, 1981.

Development of Multichannel MEG Systems in Helsinki

1984 **1986** **1989** **1992** **1998**



4 7 24 122 306



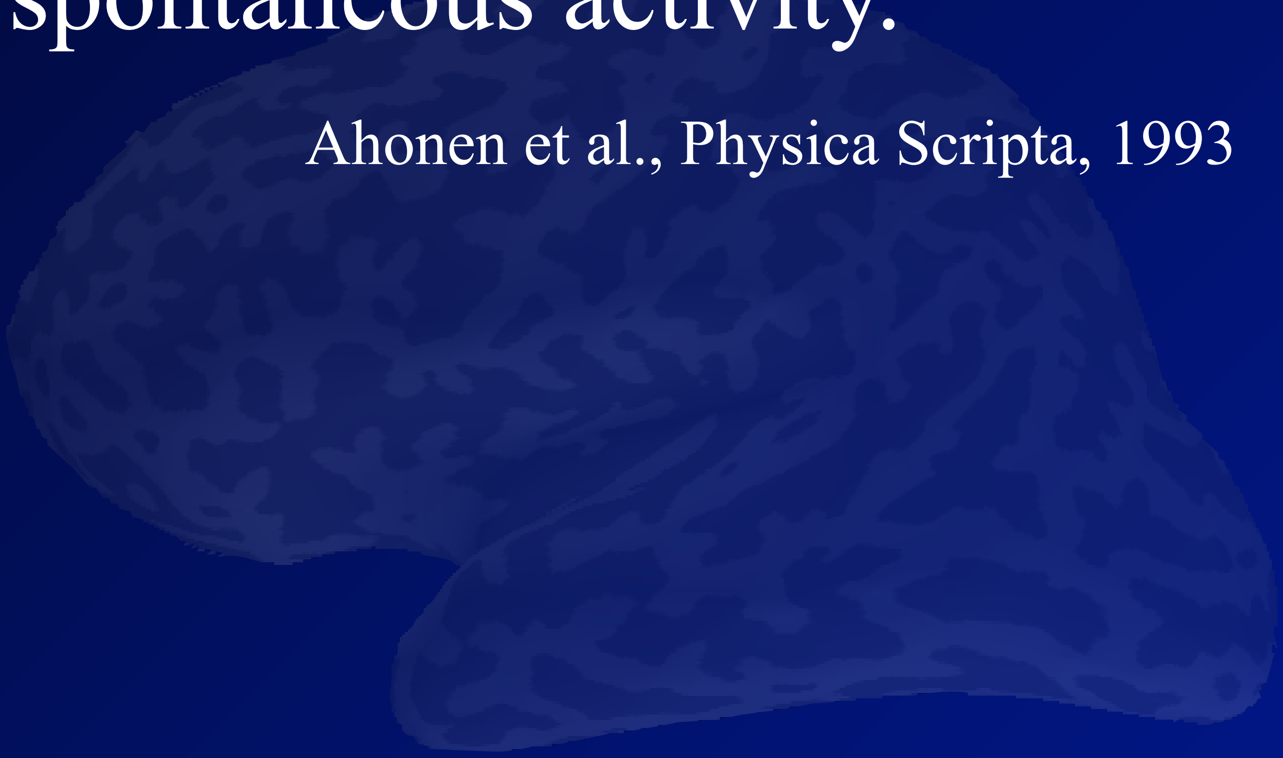
HUT

SITRA

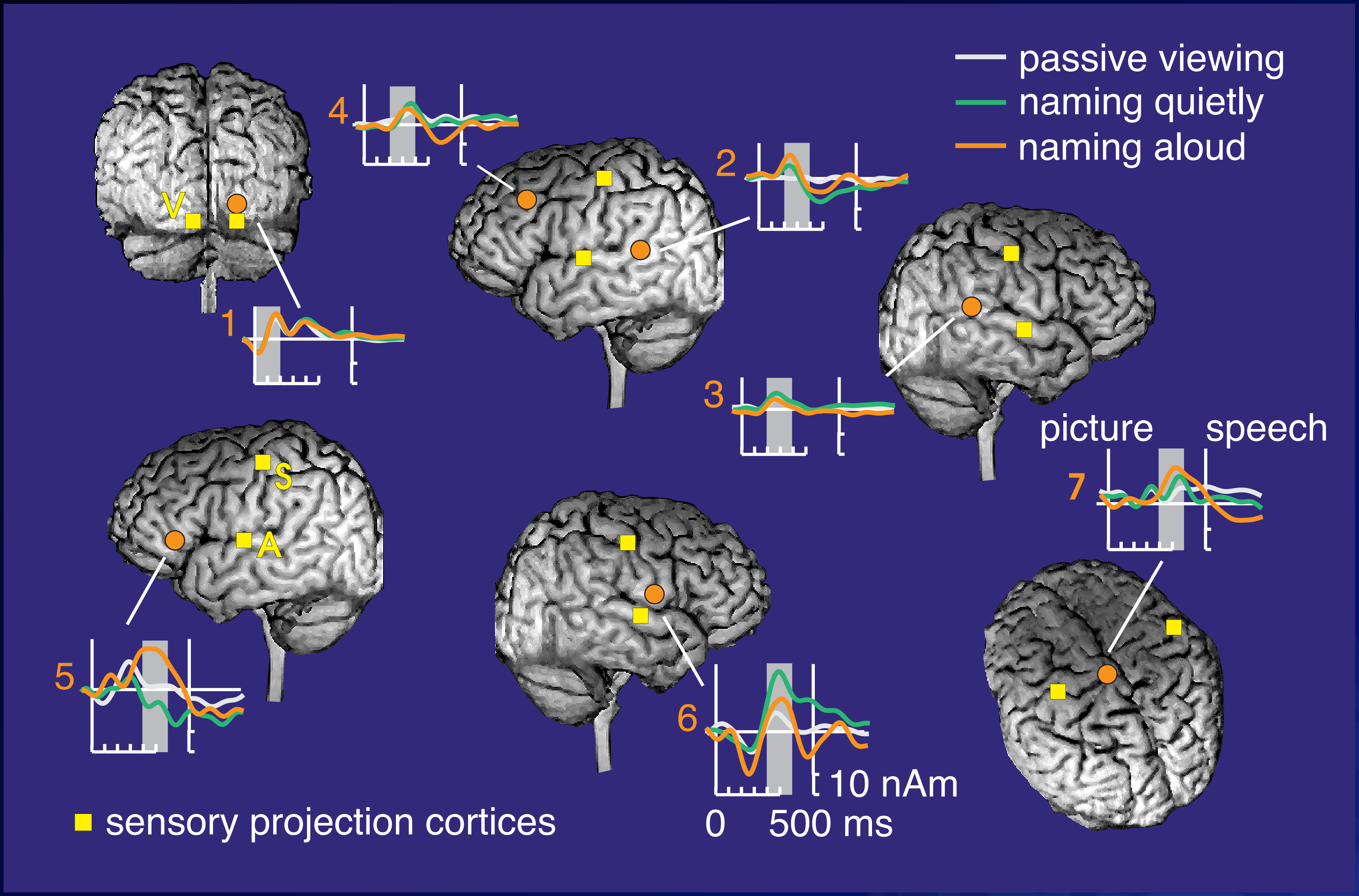
Neuromag Oy

> The recordings of magnetic fields over several brain areas simultaneously reveal qualitatively new information on the human brain and open up vast possibilities to investigate the interaction between separate brain structures in evoked studies and in the research of brain’s spontaneous activity.

Ahonen et al., Physica Scripta, 1993



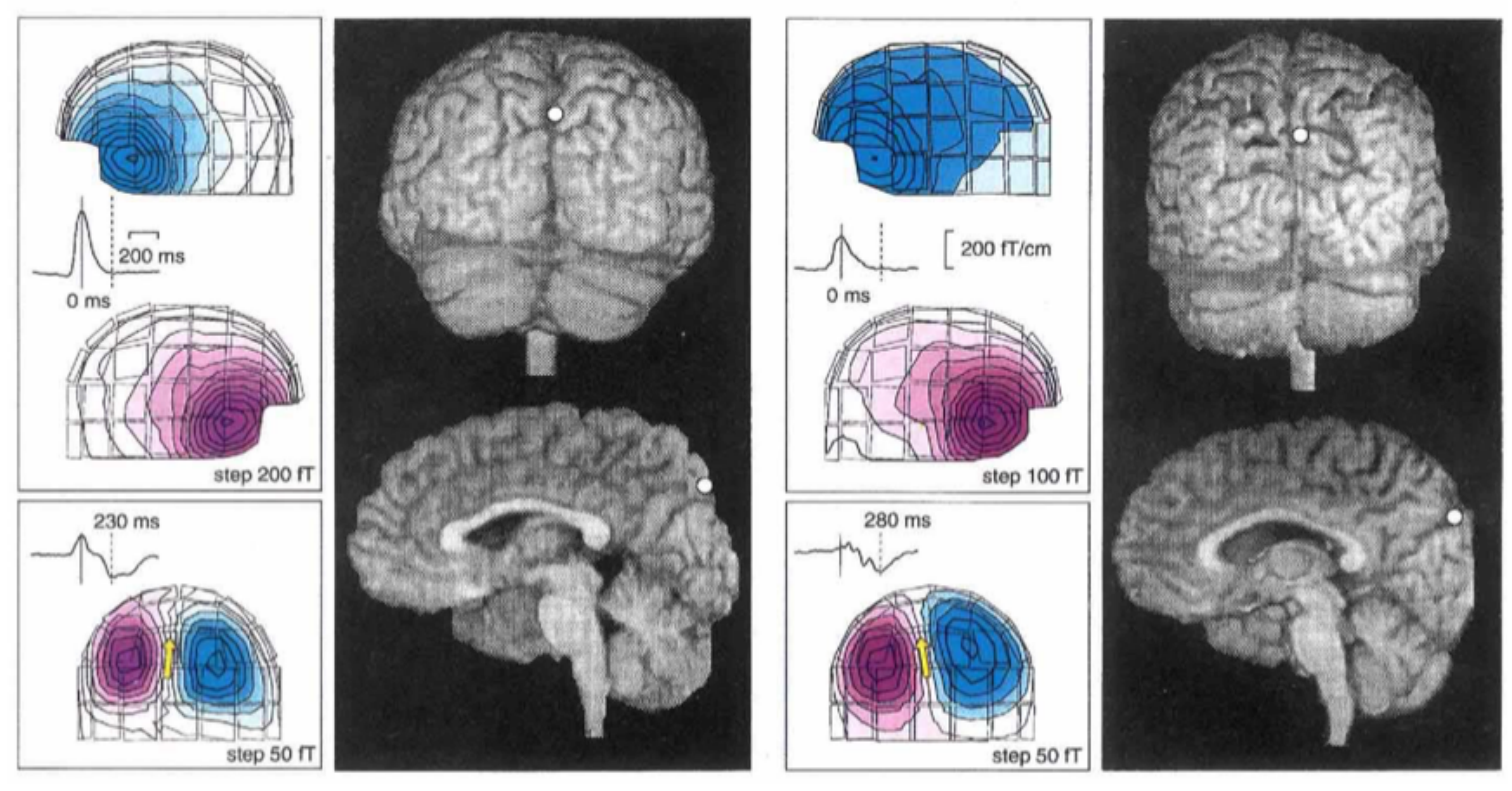
Dynamics of Cortical Activity in a Picture Naming Task



🟨 sensory projection cortices

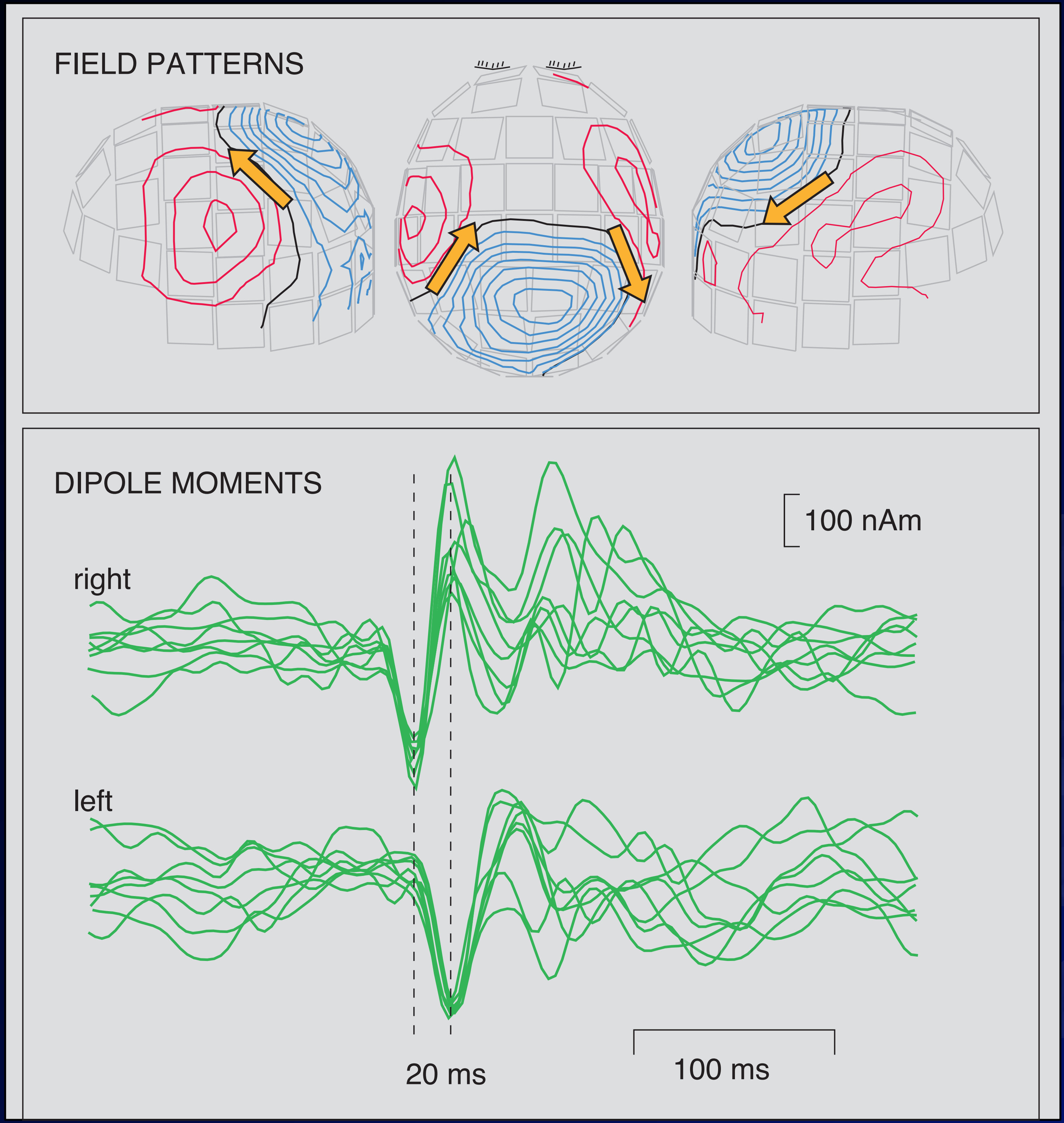
Salmelin et al., Nature, 1994

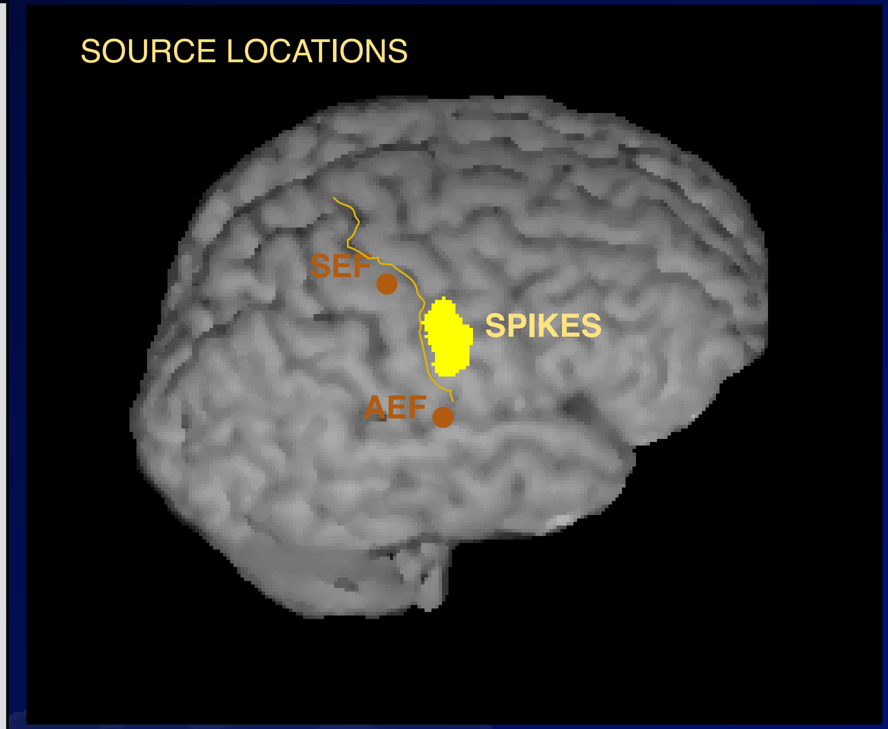
Visual Stability During Eye Blinks



Hari et al., Nature, 1994

Epileptic Spikes

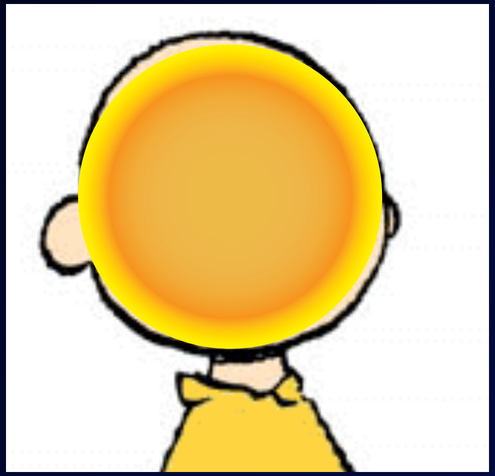




Forss et al., NeuroReport, 1993

> “Statistics are really not necessary. I only conduct experiments in which the result is clear.”
>
> Ragnar Granit

The Sphere Model



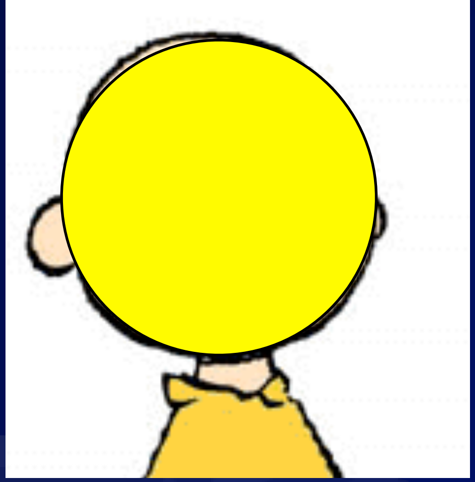
$\sigma = \sigma(r)$

MEG

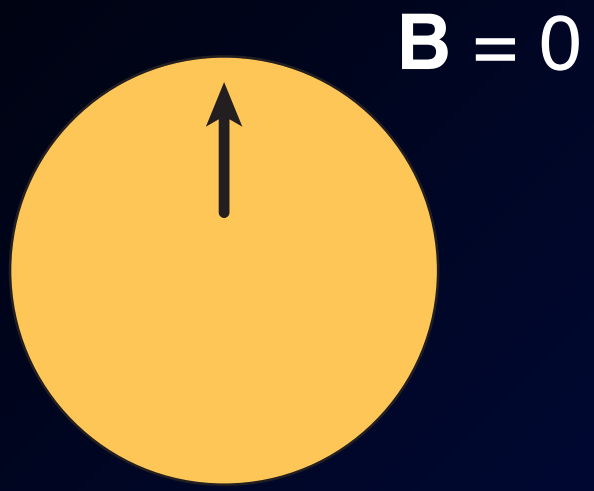
=

EEG

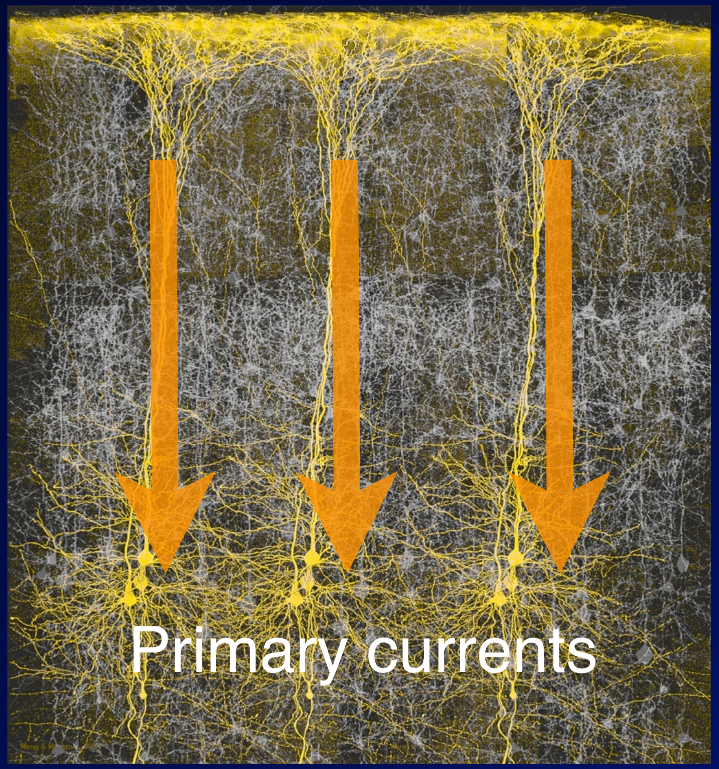
≠

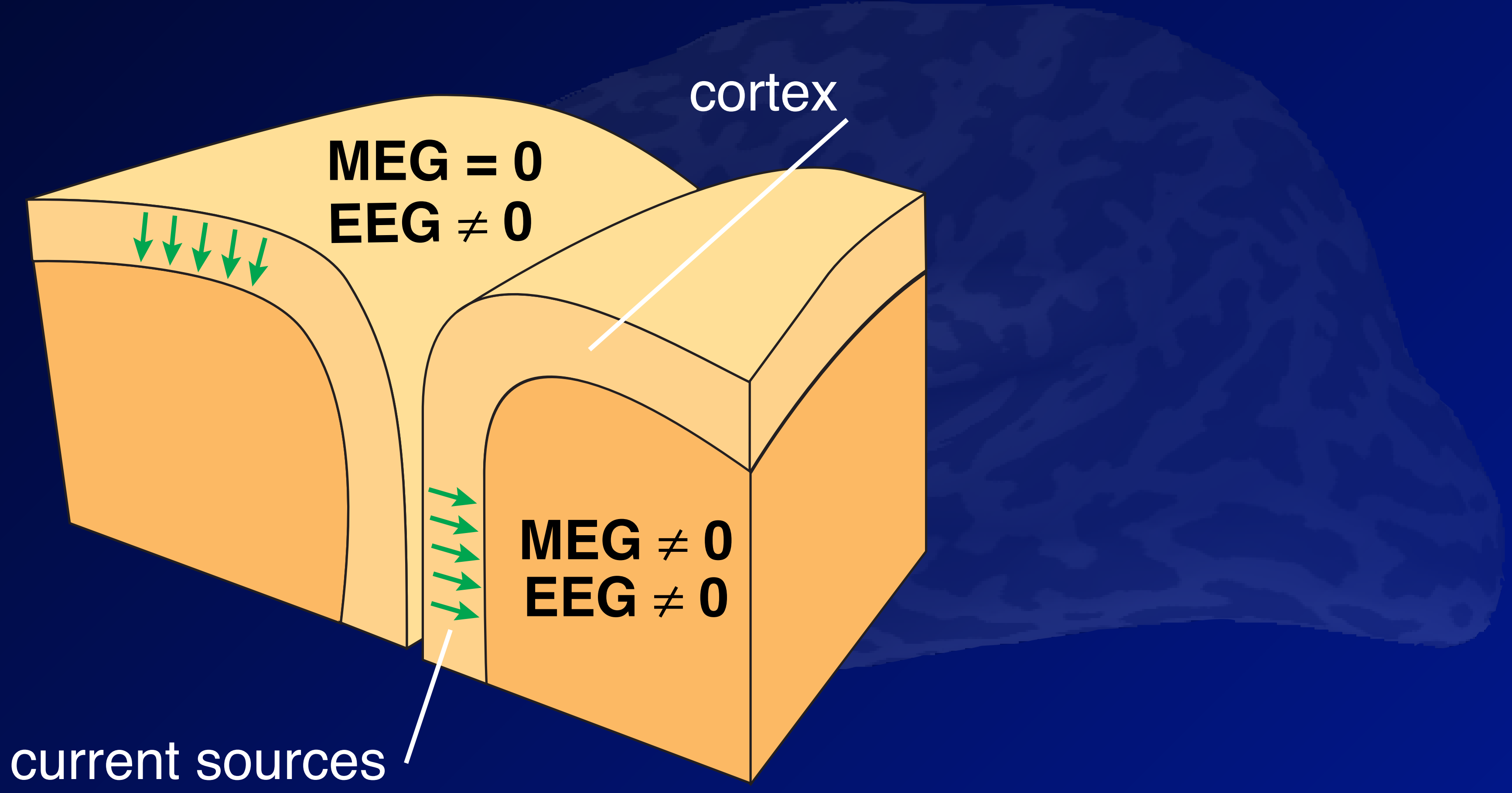


Primary currents in the cortex

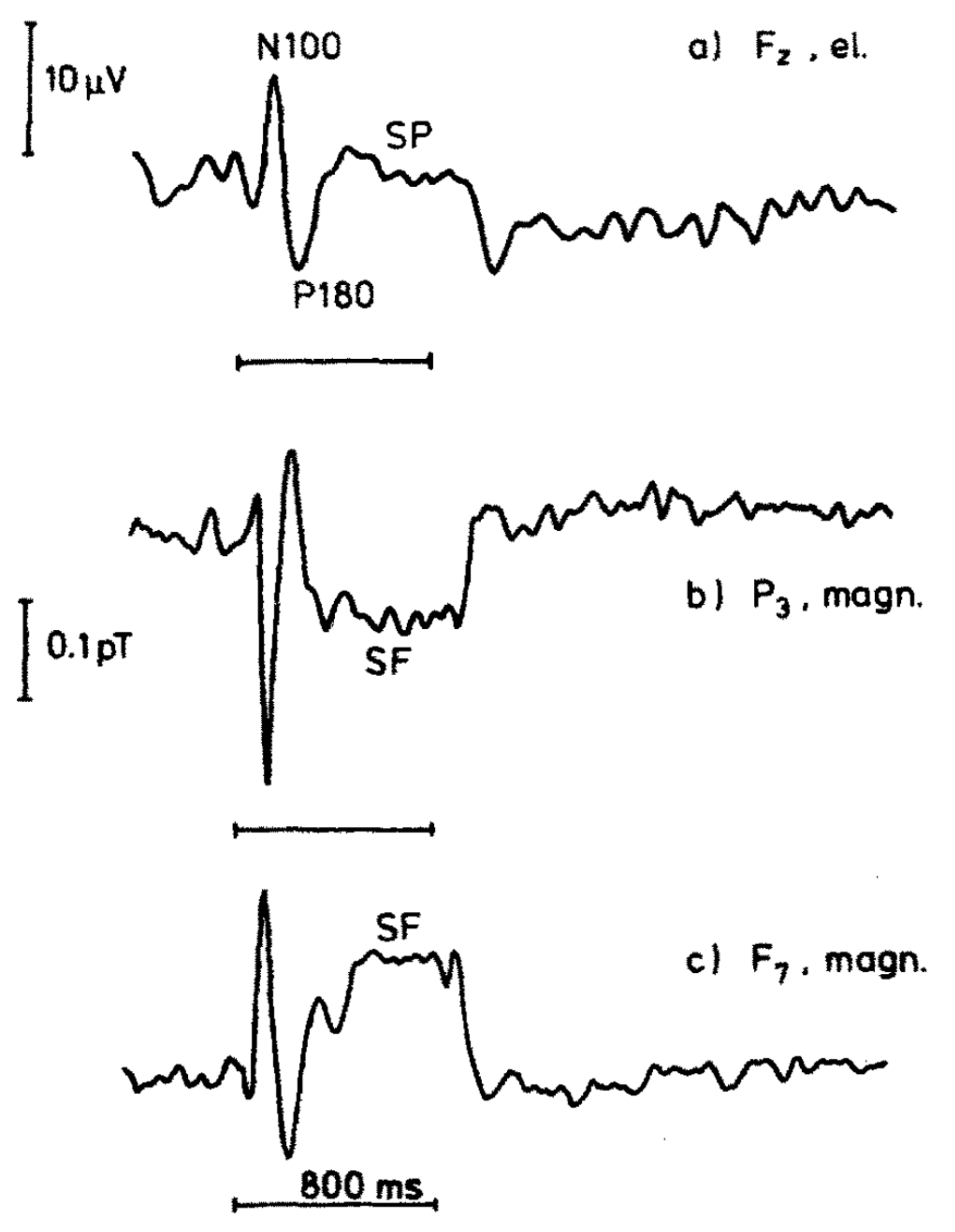


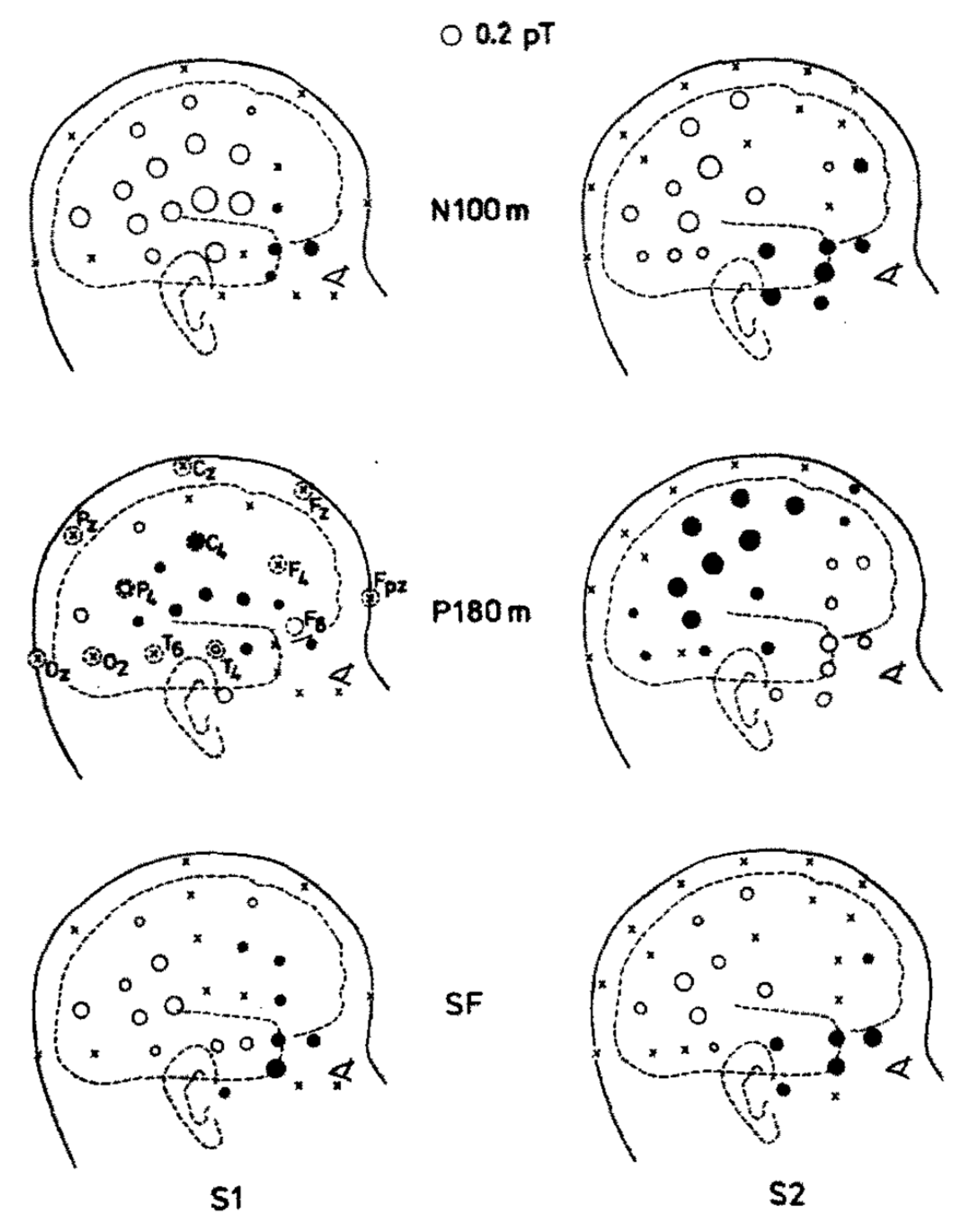
No magnetic field from radial currents in the sphere model





Auditory Responses

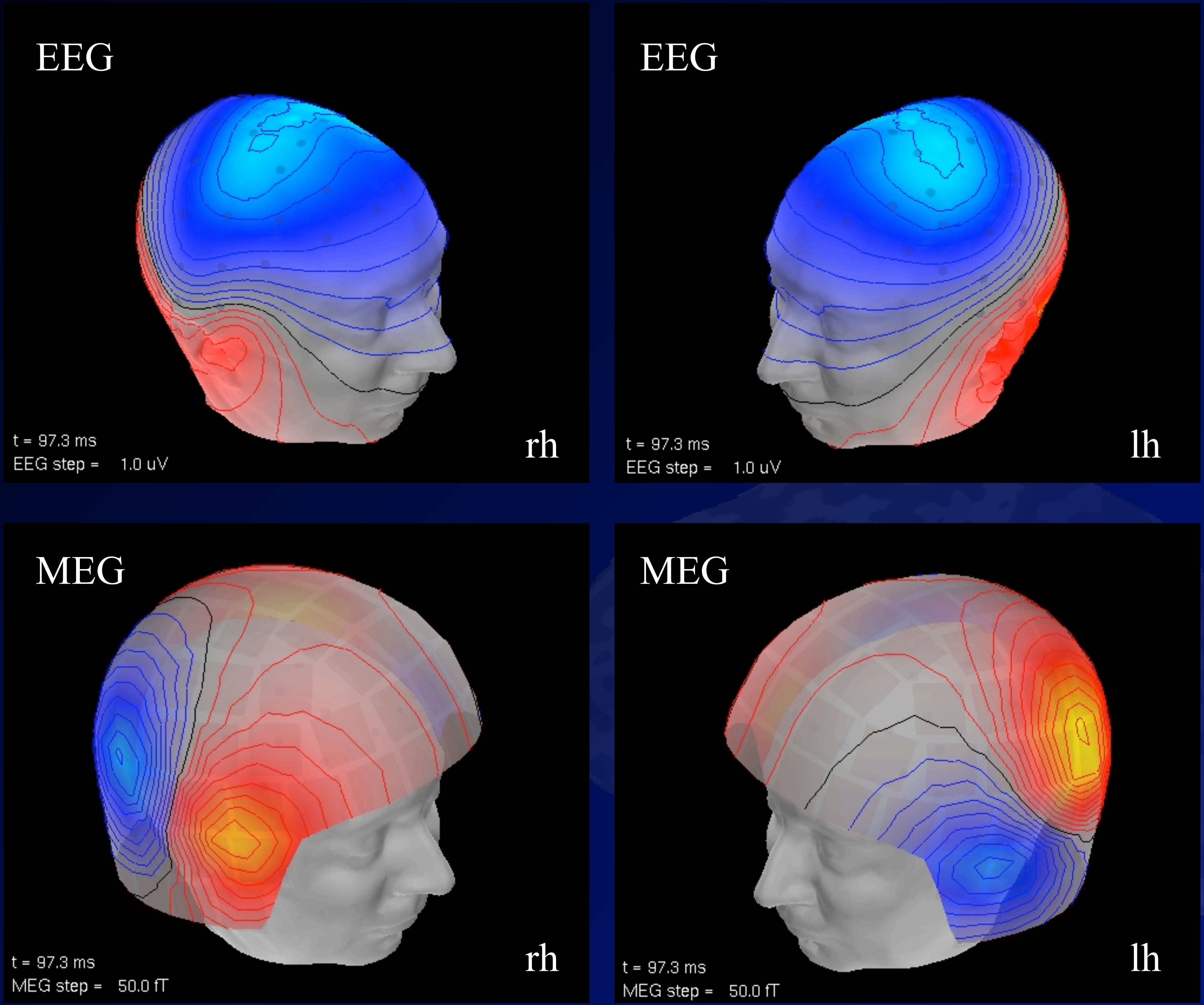




"The distributions of the magnetic fields indicate that the auditory transient evoked response at a latency 100 ms as well as the auditory sustained response are generated at and around the primary auditory cortex."

Hari et a., Exp. Brain Res., 1980

Auditory N100 in EEG and MEG



Sphere model: Early contributions

- Surface integral formulation for a piecewise homogeneous conductor

$$\vec{B} = \frac{\mu}{4\pi}\int \vec{J}_p \times \nabla' \frac{1}{R} dV' + \sum_k \Delta\sigma_k \int_{S_k} \phi \nabla' \frac{1}{R} \times d\vec{S}_k$$

Geselowitz, IEEE Trans. Magn., 1970

- No magnetic field from radial dipoles
- Layered sphere = homogeneous sphere
- No contribution from volume currents to B_r
- Closed form expressions for the magnetic field using (vector) spherical harmonics as an initial step

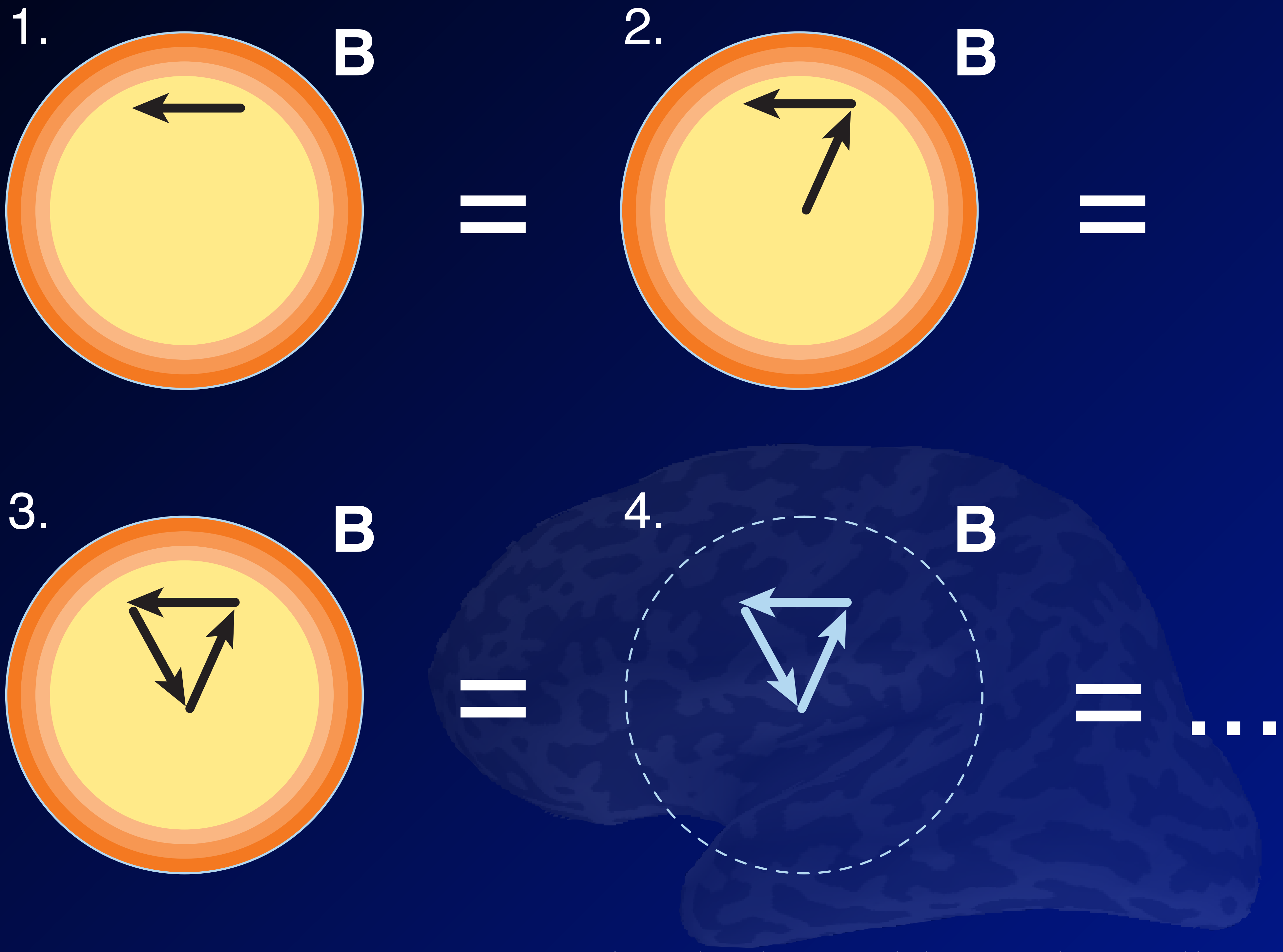
Arthur and Geselowitz, Biophys J., 1973
Cuffin and Cohen, IEEE Trans. Biomed. Eng., 1977

We analyze the forward problem in the case of the spherical model, introducing simple ways of dealing with the tangential components of the magnetic field.

Ilmoniemi, Hämäläinen, and Knuutila, 1984

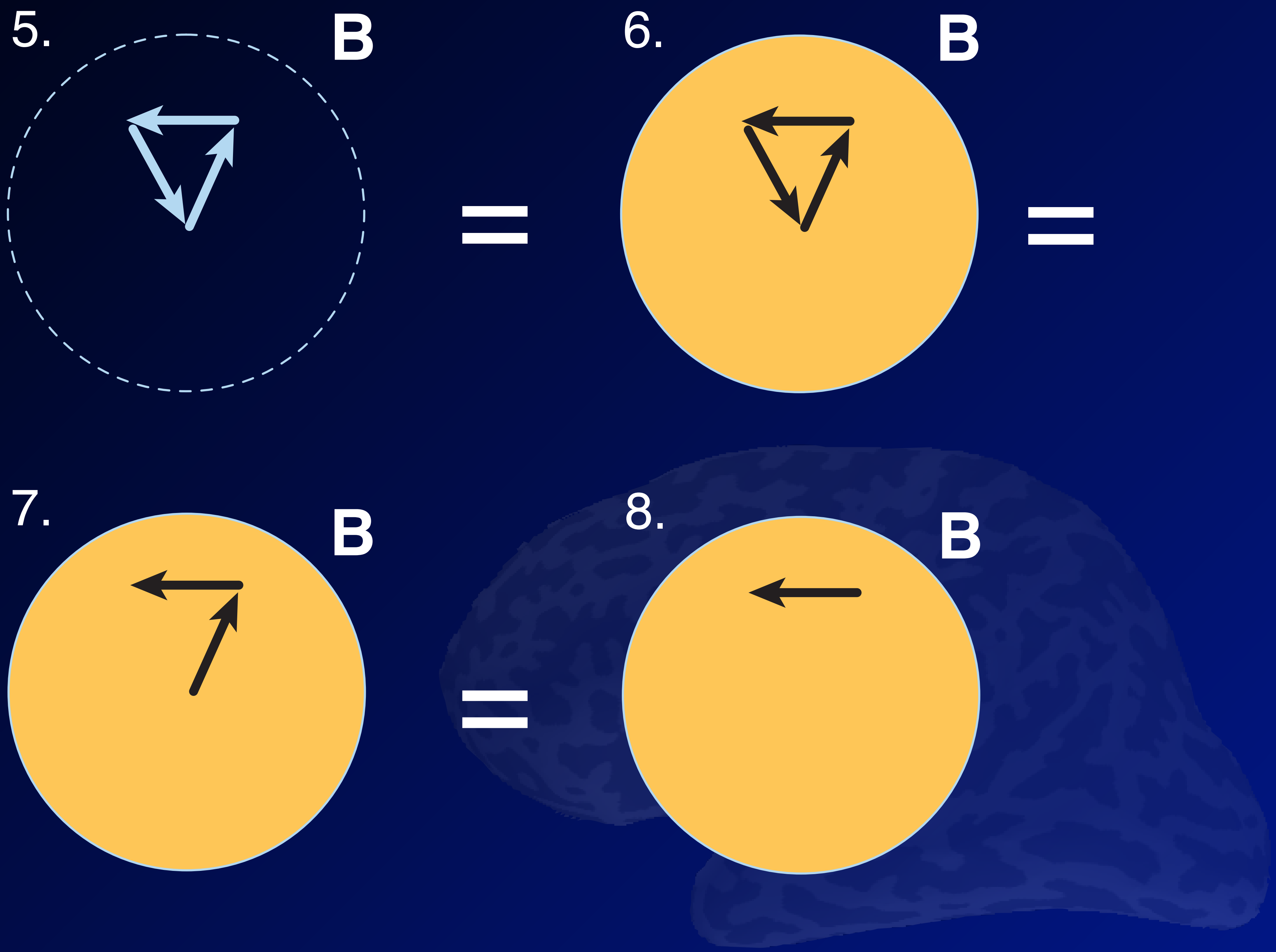
B

Dipole in a sphere: Add radial sources

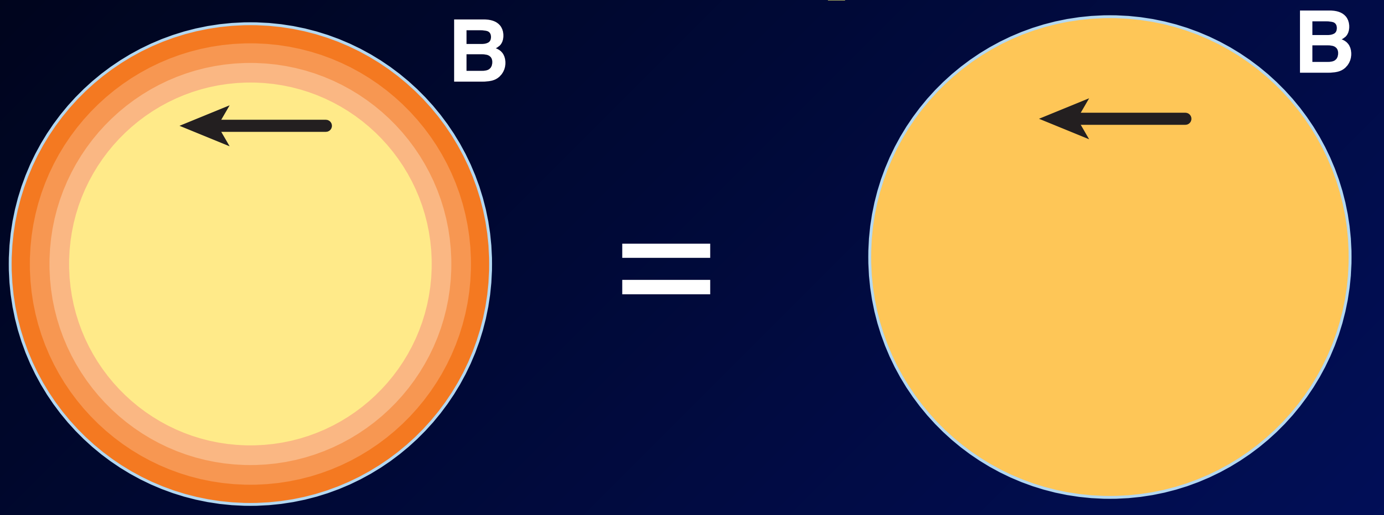


Ilmoniemi, Hämäläinen and Knuutila, 1984

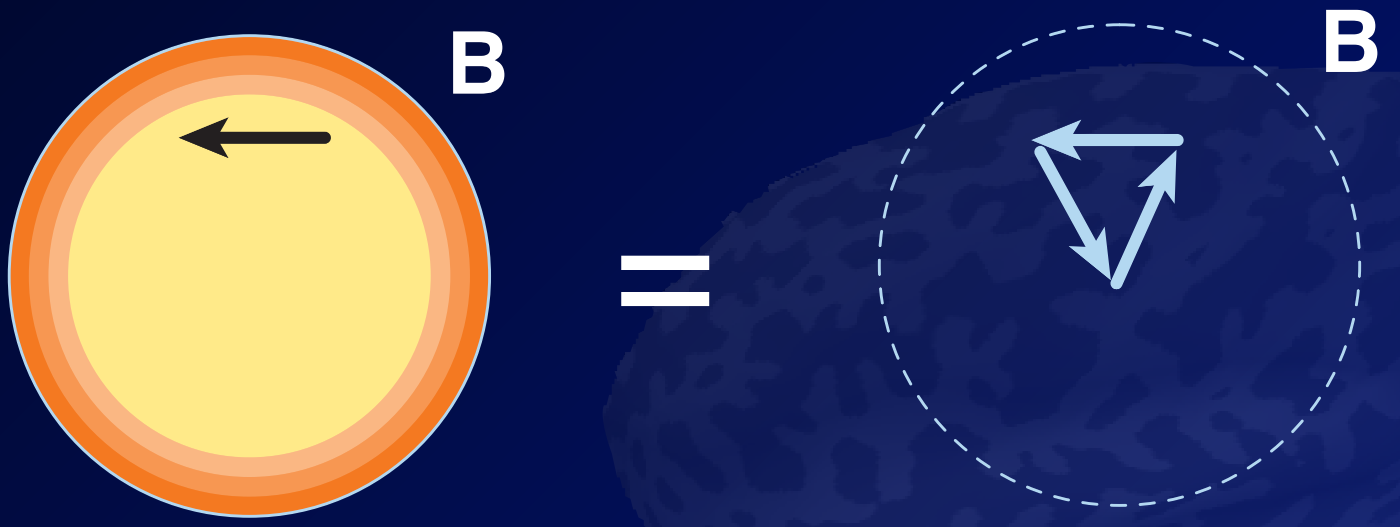
Change to a homogeneous sphere



Summary of the sphere model graph theory



Conductivity profile is irrelevant

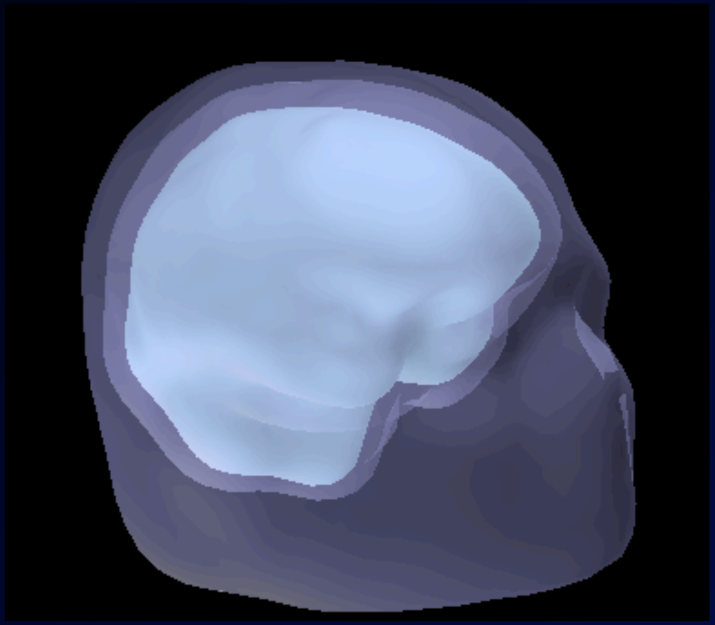


Simplified forward calculation

A dry phantom can be constructed

Ilmoniemi, Hämäläinen and Knuutila, 1984

The Homogeneous Head Model



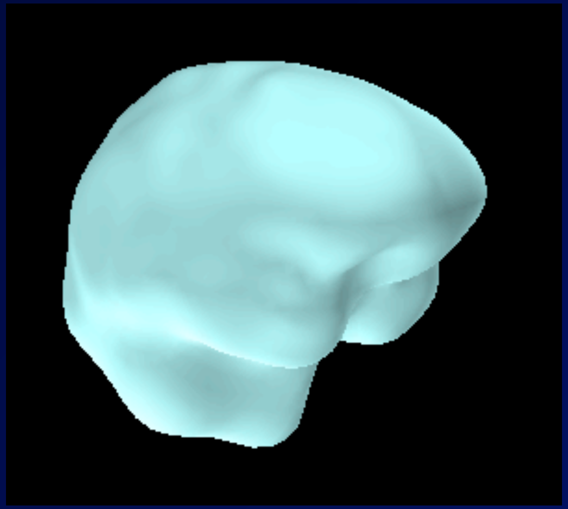
Skull and scalp taken into account

MEG

$\approx$

EEG

$\neq$

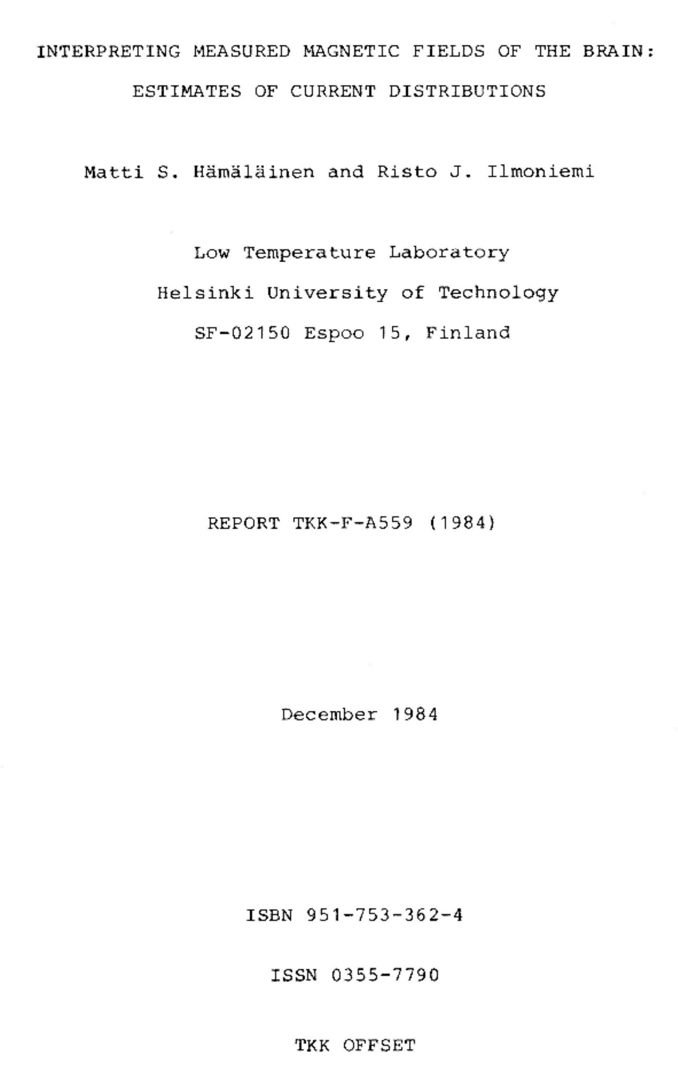


Homogeneous model:
skull taken as an insulator

It is numerically shown that for the computation of ***B***, produced by cerebral current sources, it is sufficient to consider a brain-shaped homogeneous conductor only. Comparisons with the sphere model are also included to pinpoint areas where the homogeneous conductor model provides essential improvements in the calculation of the magnetic field outside the head.

Hämäläinen and Sarvas, 1989

First MNE



INTERPRETING MEASURED MAGNETIC FIELDS OF THE BRAIN:
ESTIMATES OF CURRENT DISTRIBUTIONS

Matti S. Hämäläinen and Risto J. Ilmoniemi

Low Temperature Laboratory
Helsinki University of Technology
SF-02150 Espoo 15, Finland

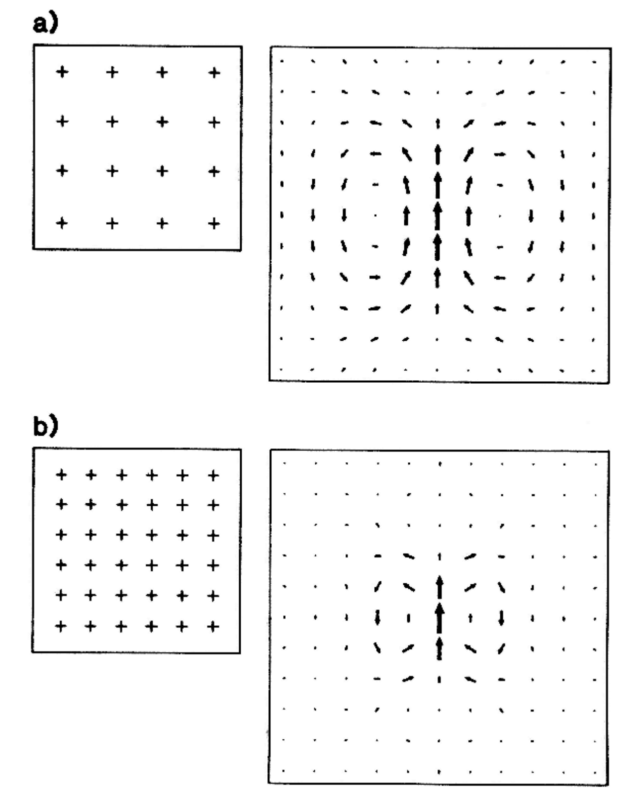
REPORT TKK-F-A559 (1984)

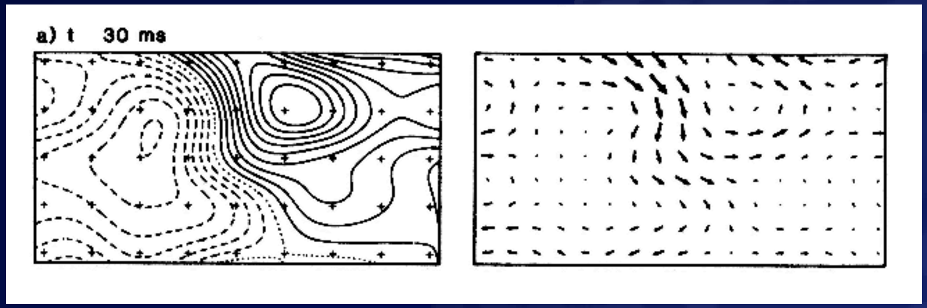
December 1984

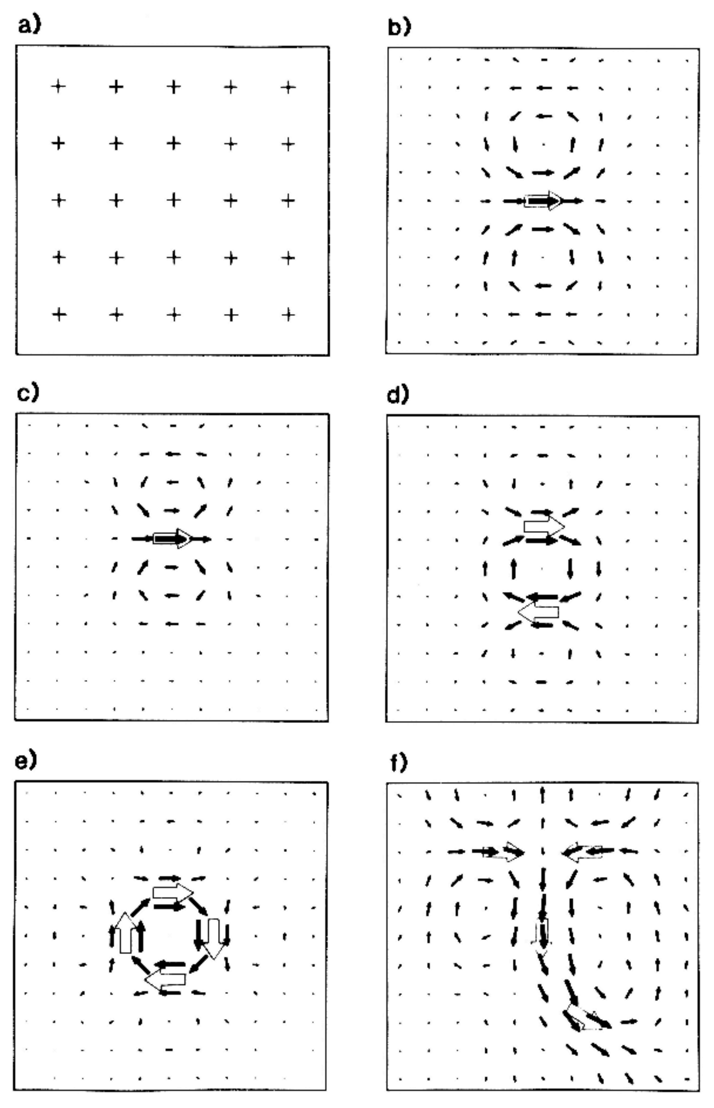
ISBN 951-753-362-4

ISSN 0355-7790

TKK OFFSET



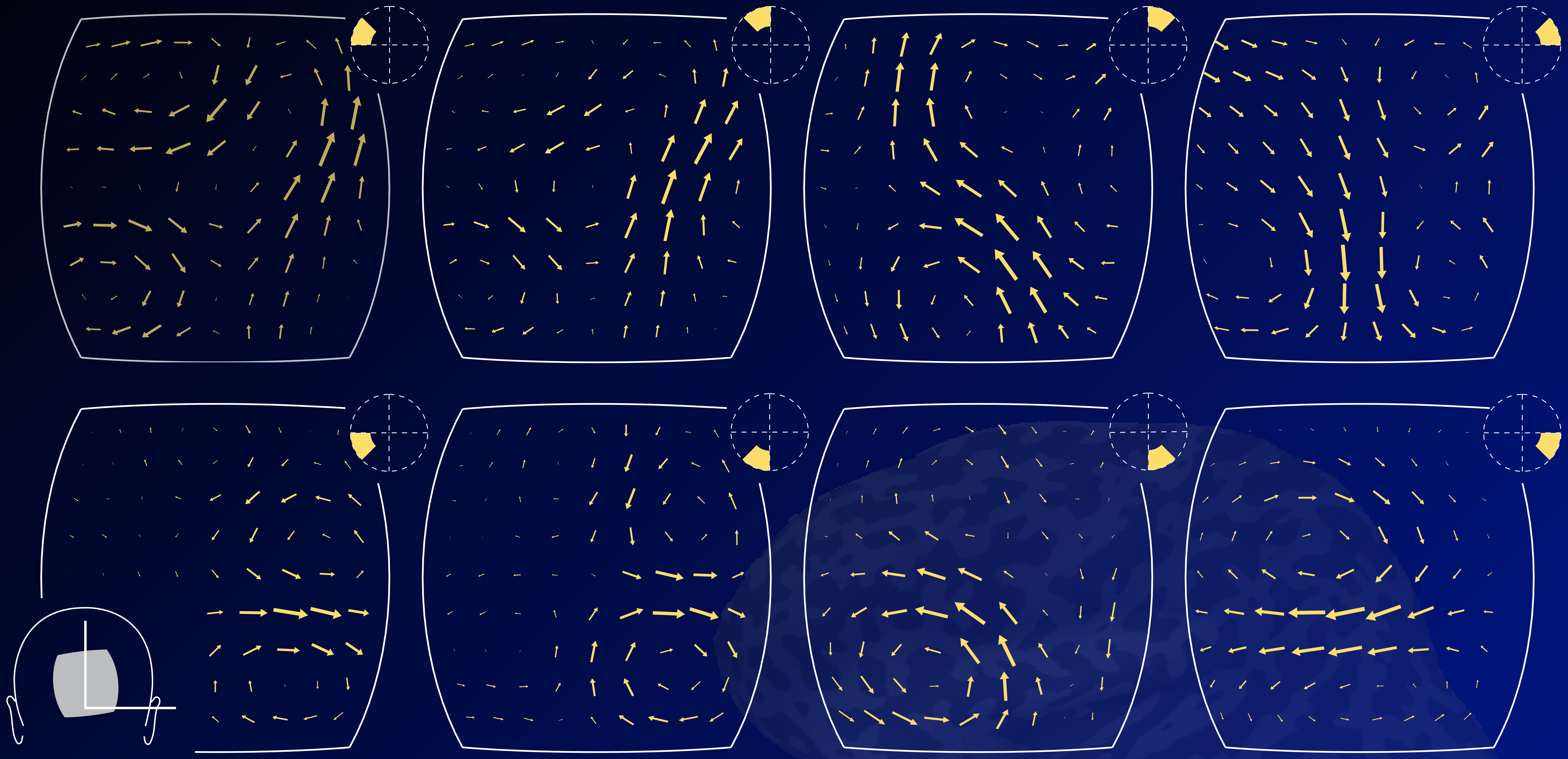




It would be desirable to improve the minimum norm estimates by finding ways to inject some a priori knowledge or assumptions of the experimenter. For example, one could confine the integration area to be the cortex, or one could require that the event in the brain be local.

Hämäläinen and Ilmoniemi, 1984

Retinotopic mapping with MNE



MEG array

Peripheral checkerboard octant stimuli, t = 80 ms

Ahlfors *et al.* 1992

Are we still having fun?

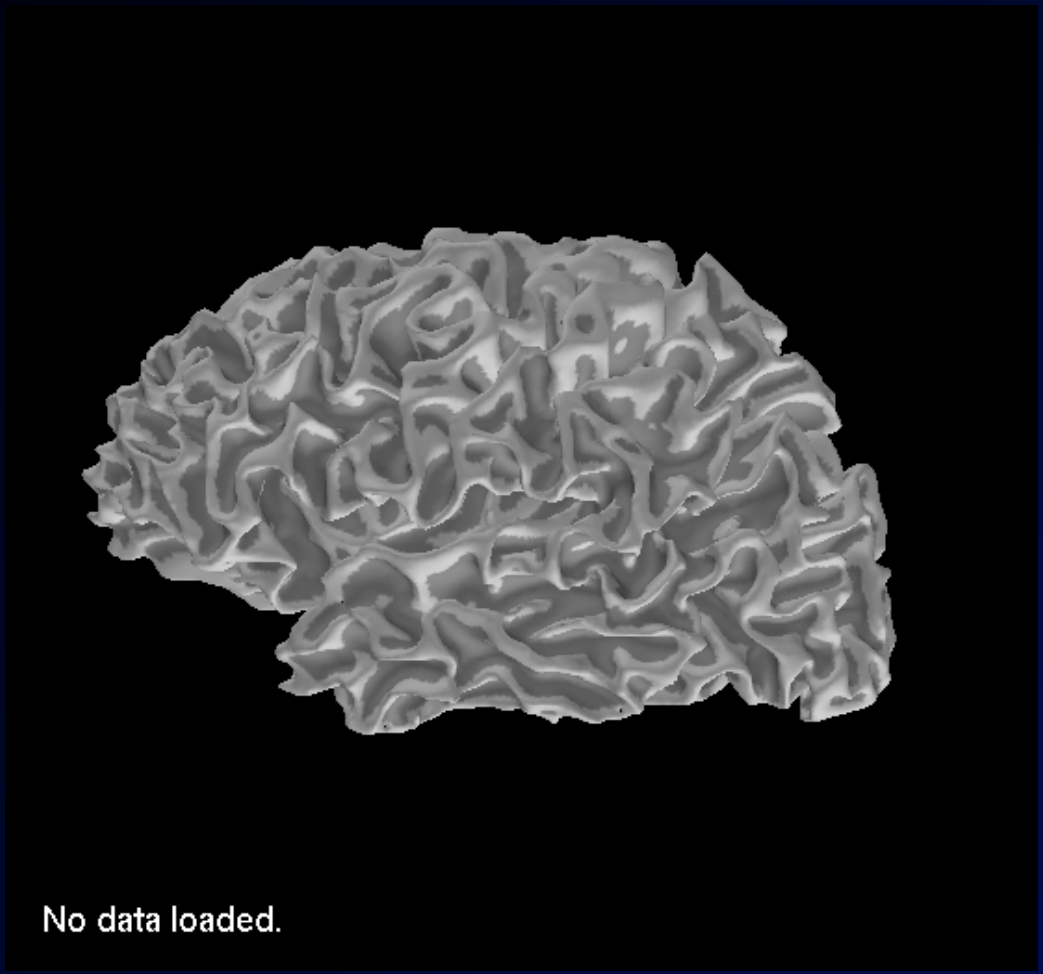
Jack Belliveau (MGH)

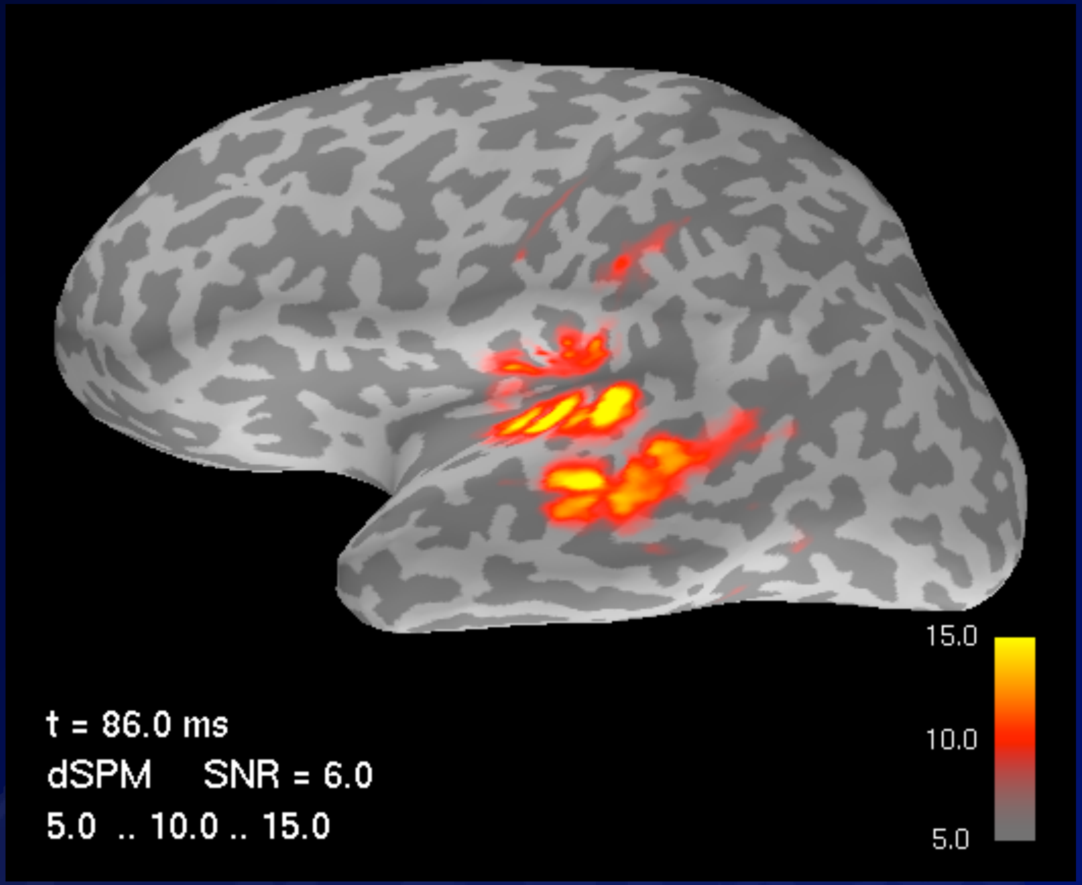
- It is necessary and possible to combine multiple imaging modalities to benefit from their complementary strengths

Anders Dale

- Computational models of anatomy based on MRI
- First anatomically-constrained minimum-norm solutions (1993)

Inflated Cortex



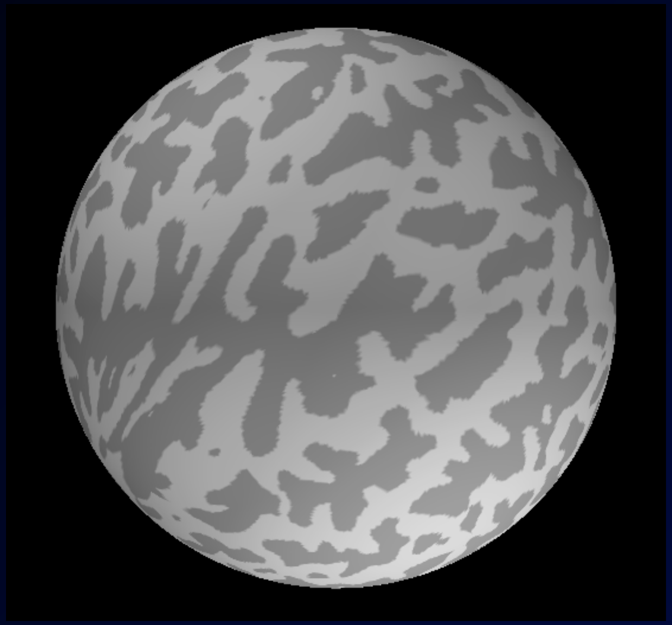


The recovery of the topology of the cortical manifold makes it possible to conveniently view the solutions (as well as data from other activity imaging techniques) after gently “inflating” the brain, as well as allowing more effective intersubject comparisons.

Dale and Sereno 1993

Inflation to a Sphere and Registration

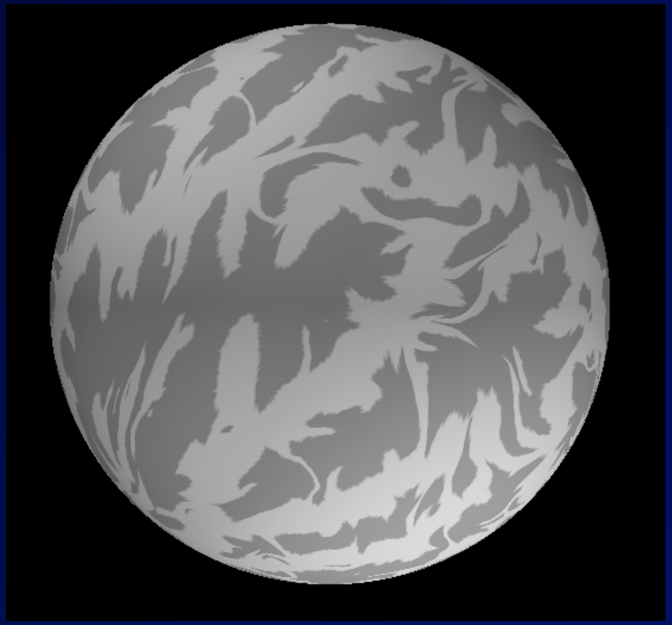
Individual



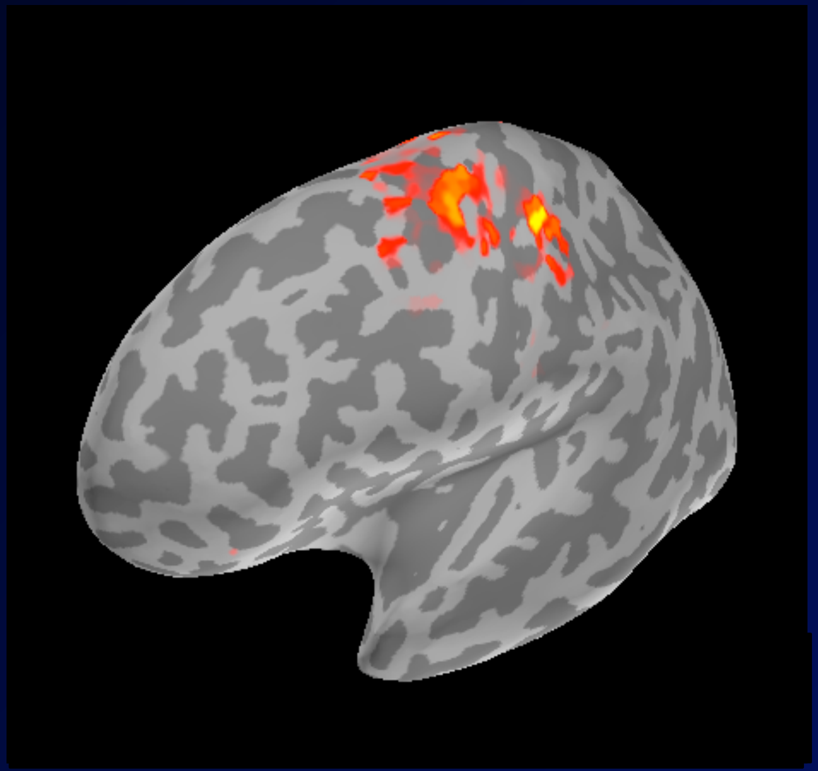
Align sulcal patterns

to the average brain

Aligned with average brain

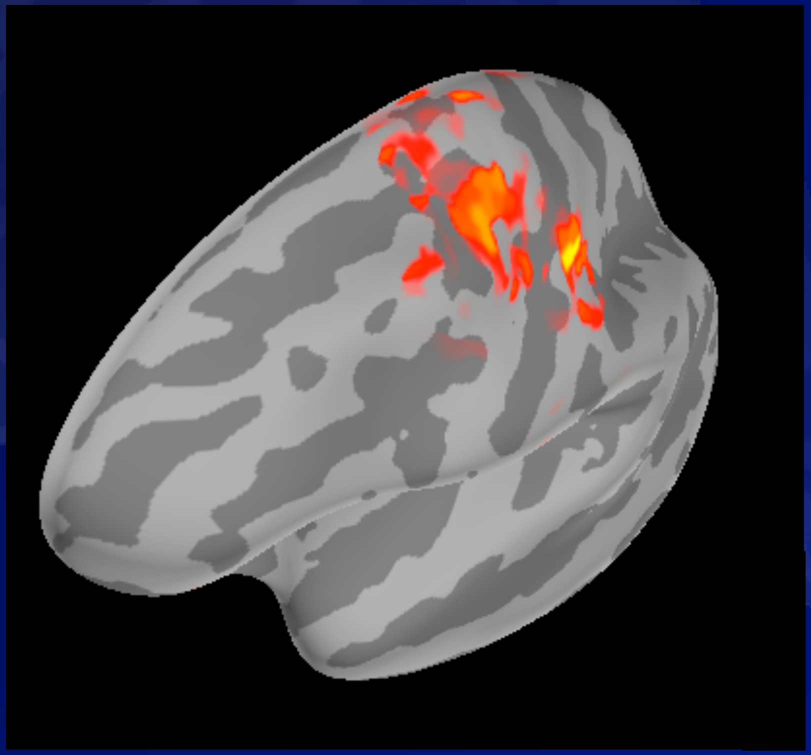


MEG activity estimate

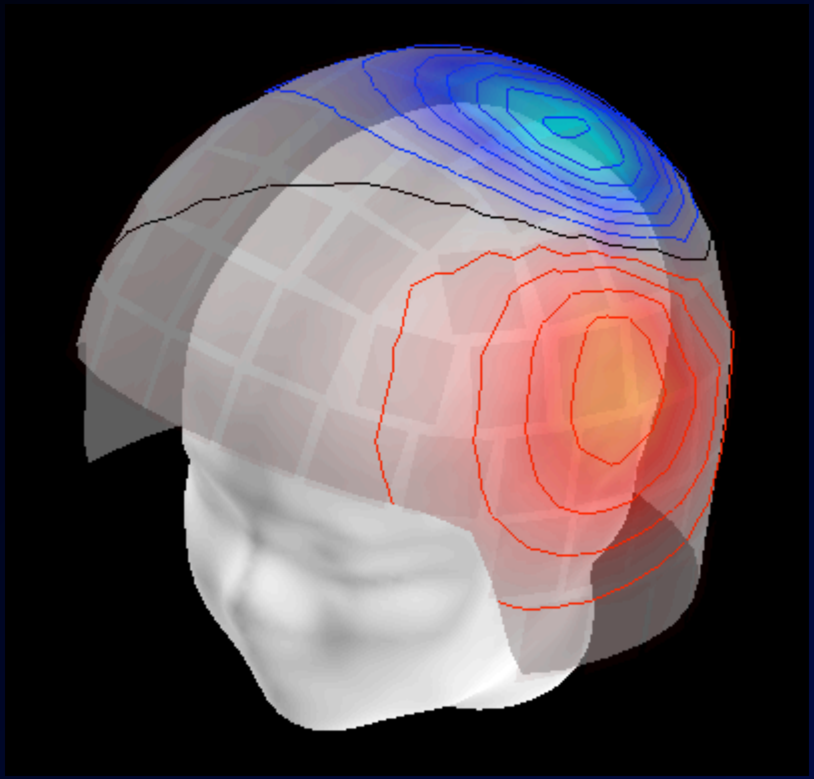


Morph

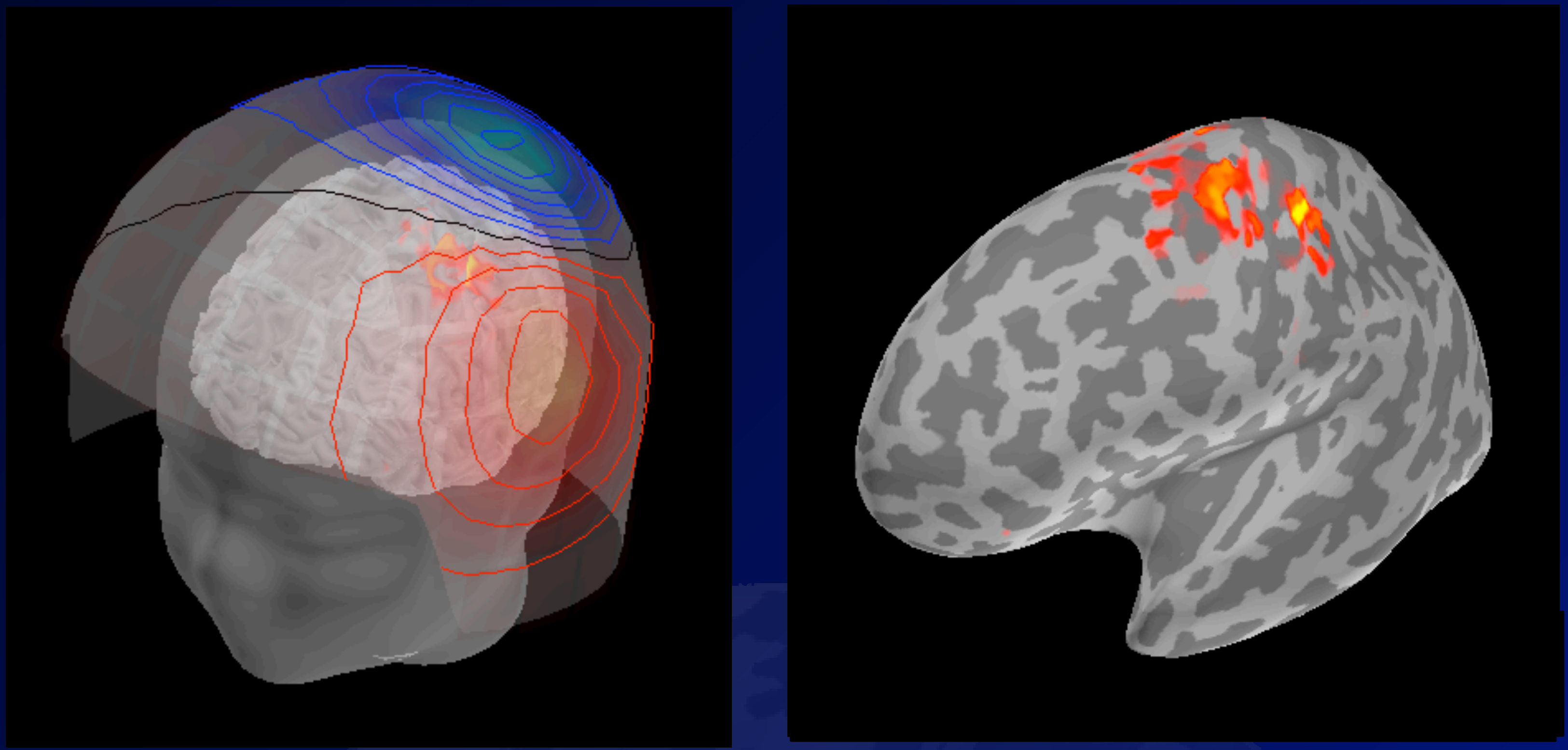
Mapped to the average brain



Source (brain) space instead of sensor space

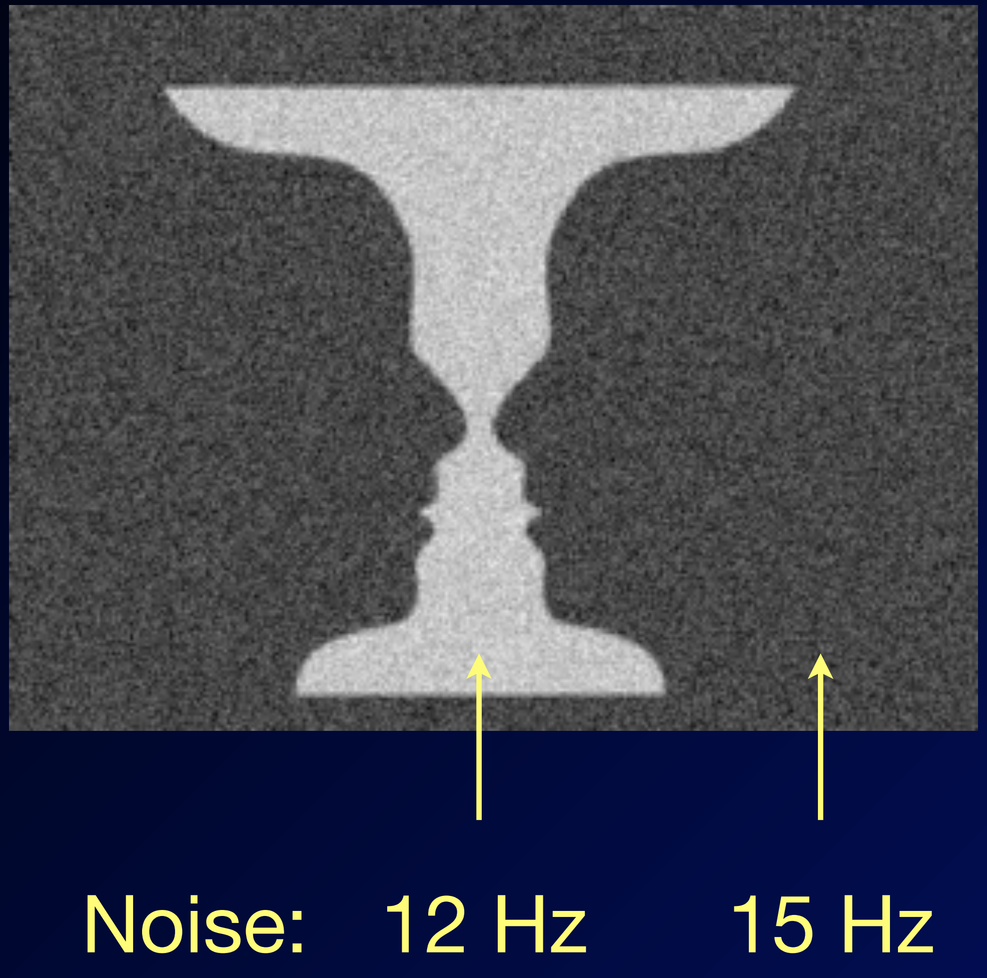


Sensor space map

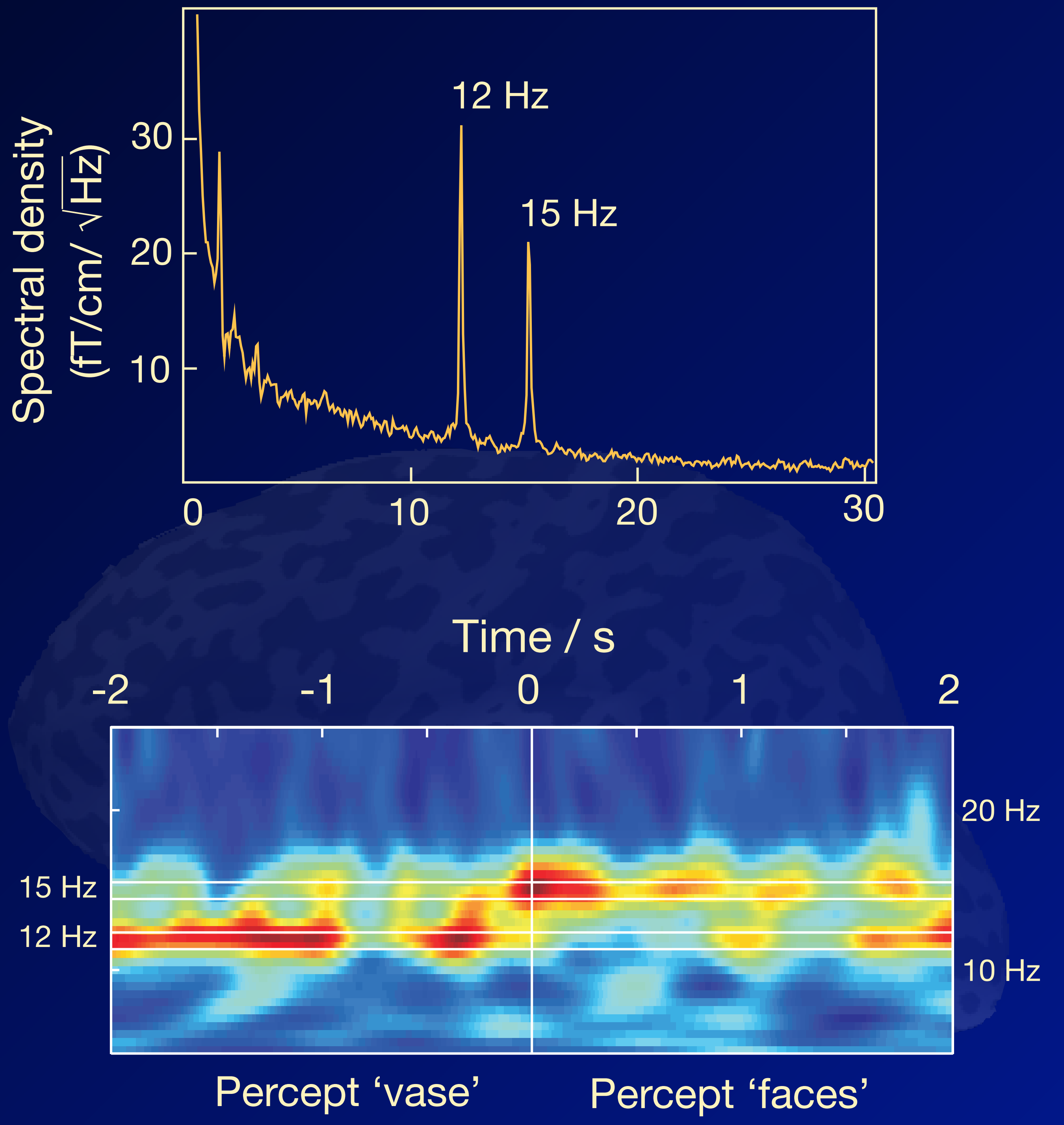


Source estimates

Visual percepts of an ambiguous scene



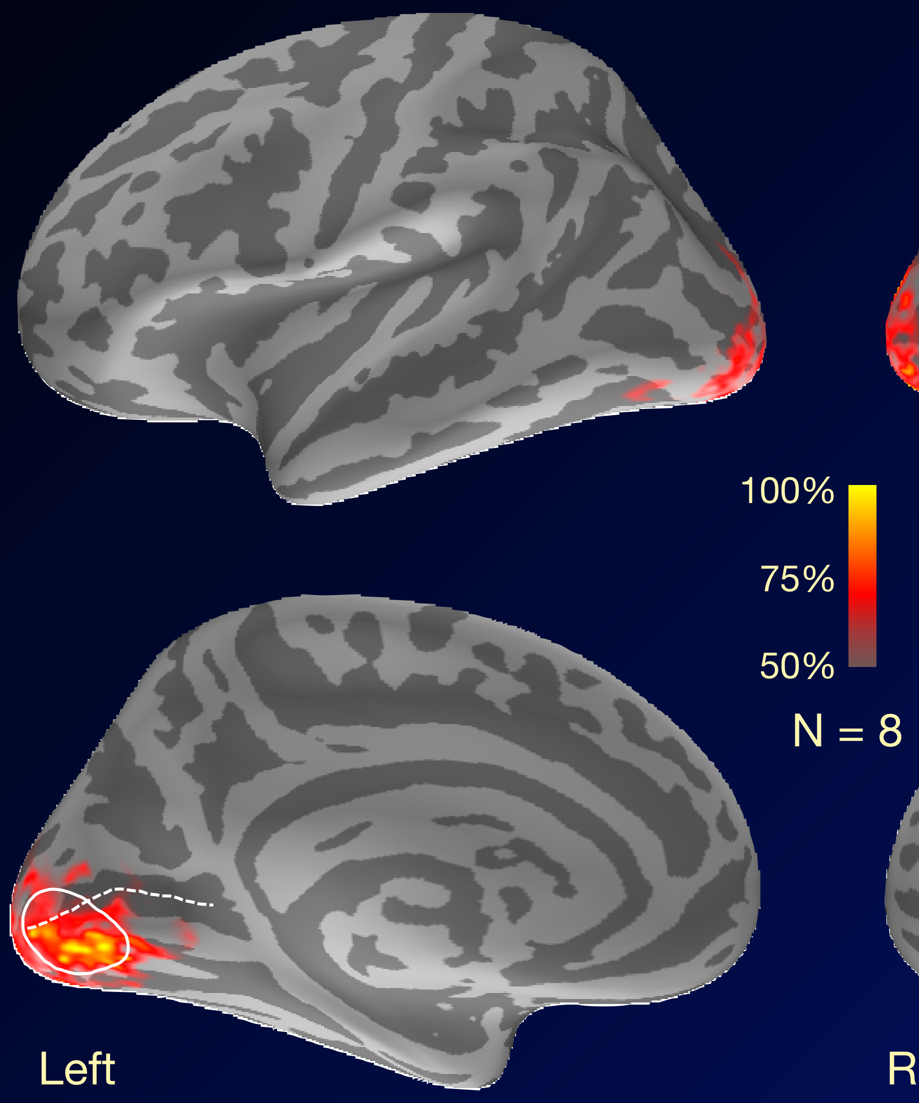
MEG signals at an occipital sensor



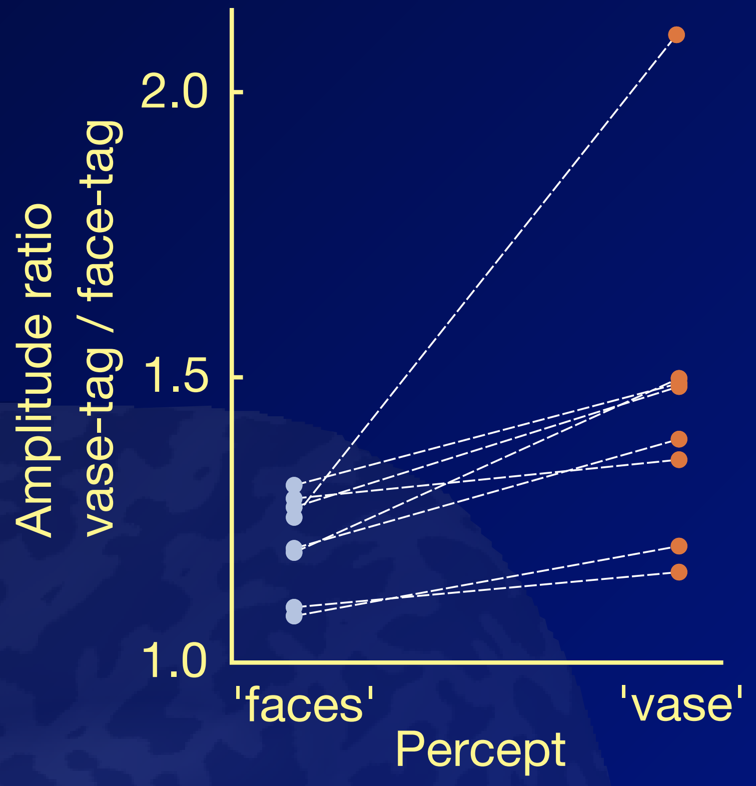
Parkkonen *et al.*, PNAS, 2008

Group analysis

Significant activity in either tag frequency



Amplitude ratio at ROI

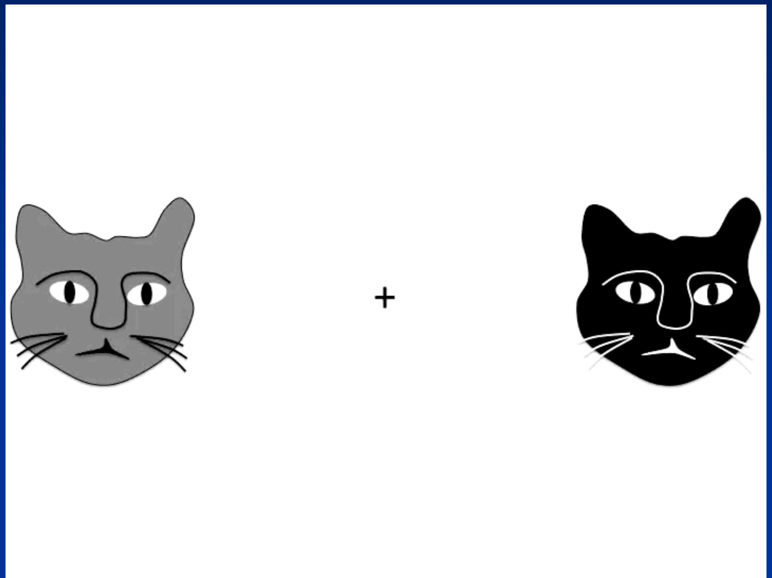


Parkkonen *et al.*, PNAS, 2008

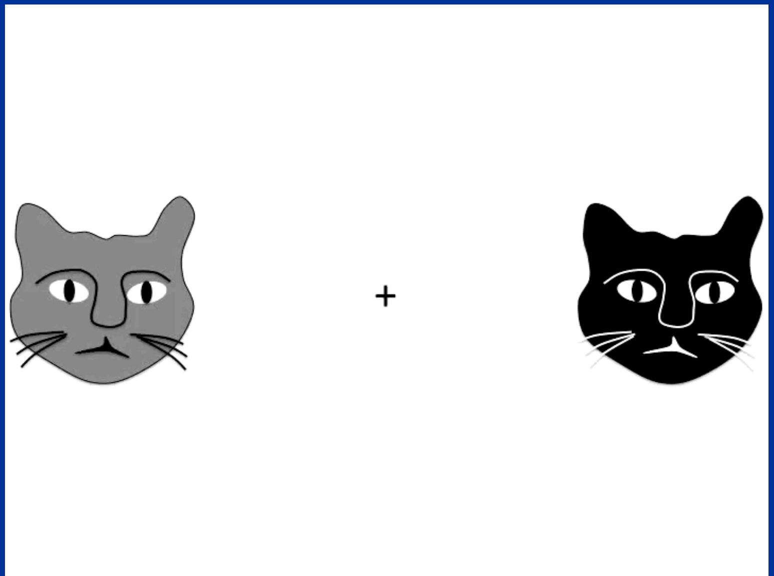
Interacting parallel pathways associate sounds with visual identity in auditory cortices

Object tracking task trials

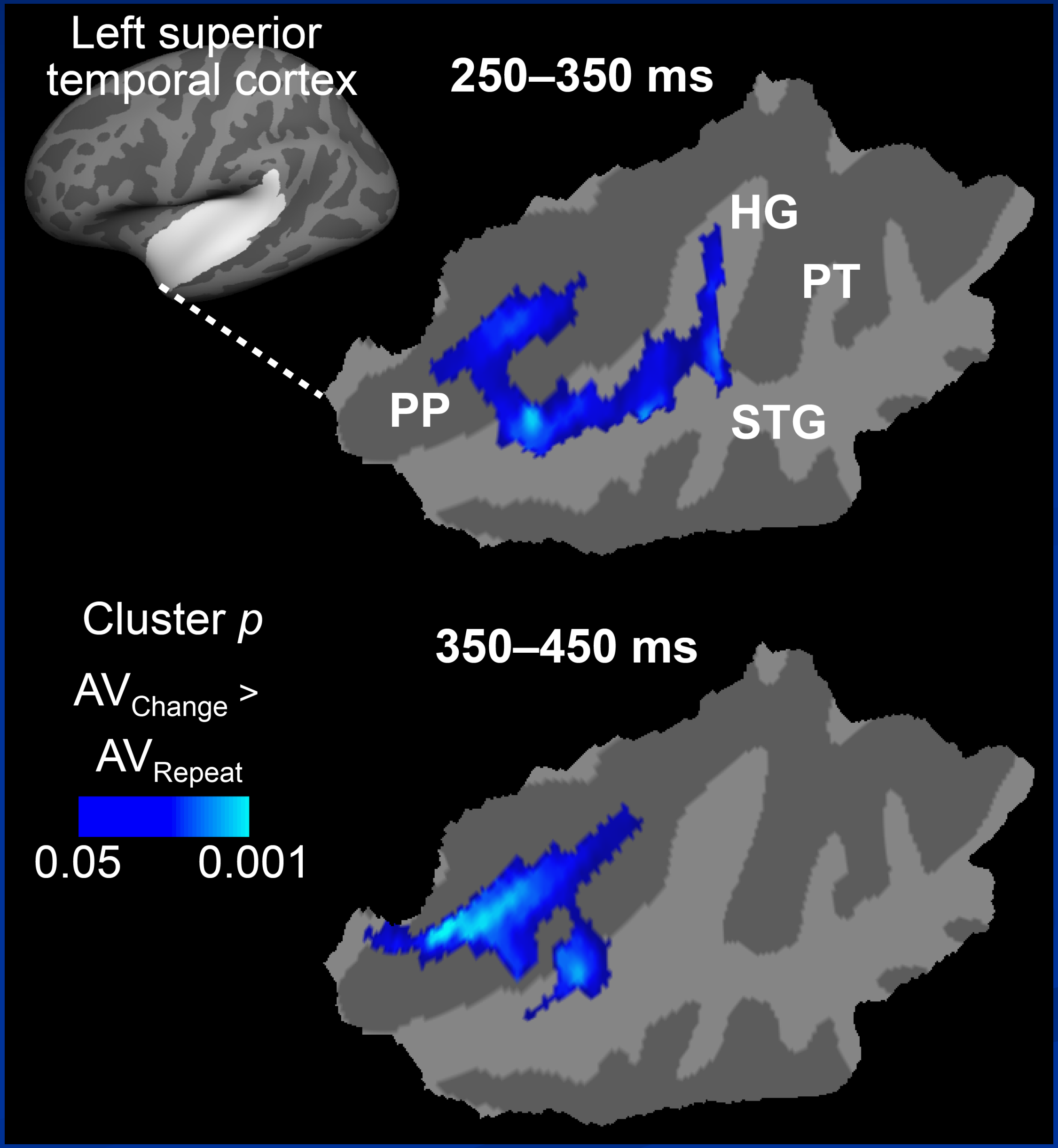
Visual identity and voice unchanged (AV_{Repeat})



Visual identity changes, voice unchanged (AV_{Change})

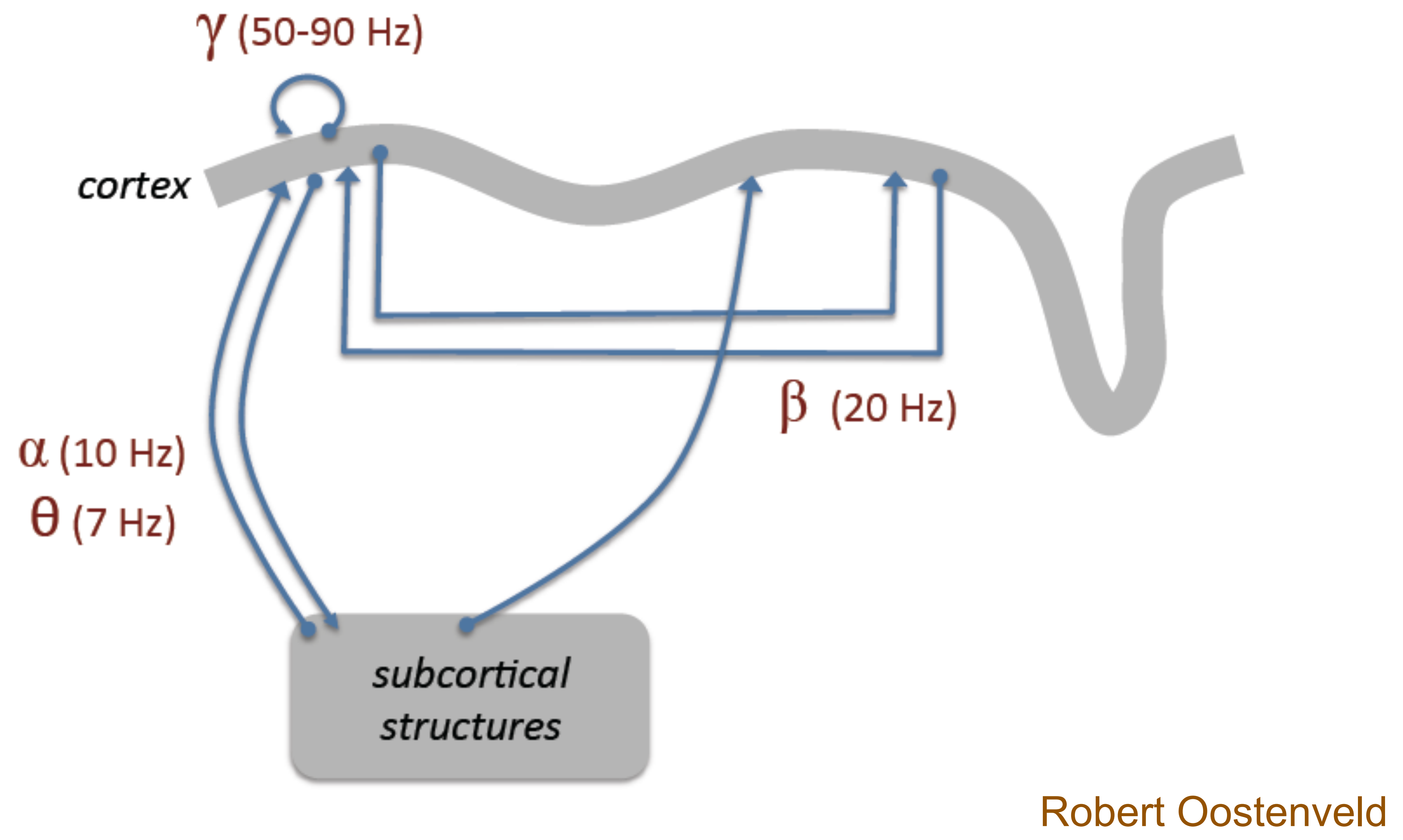


Effects of *visual* identity changes in *auditory* cortex



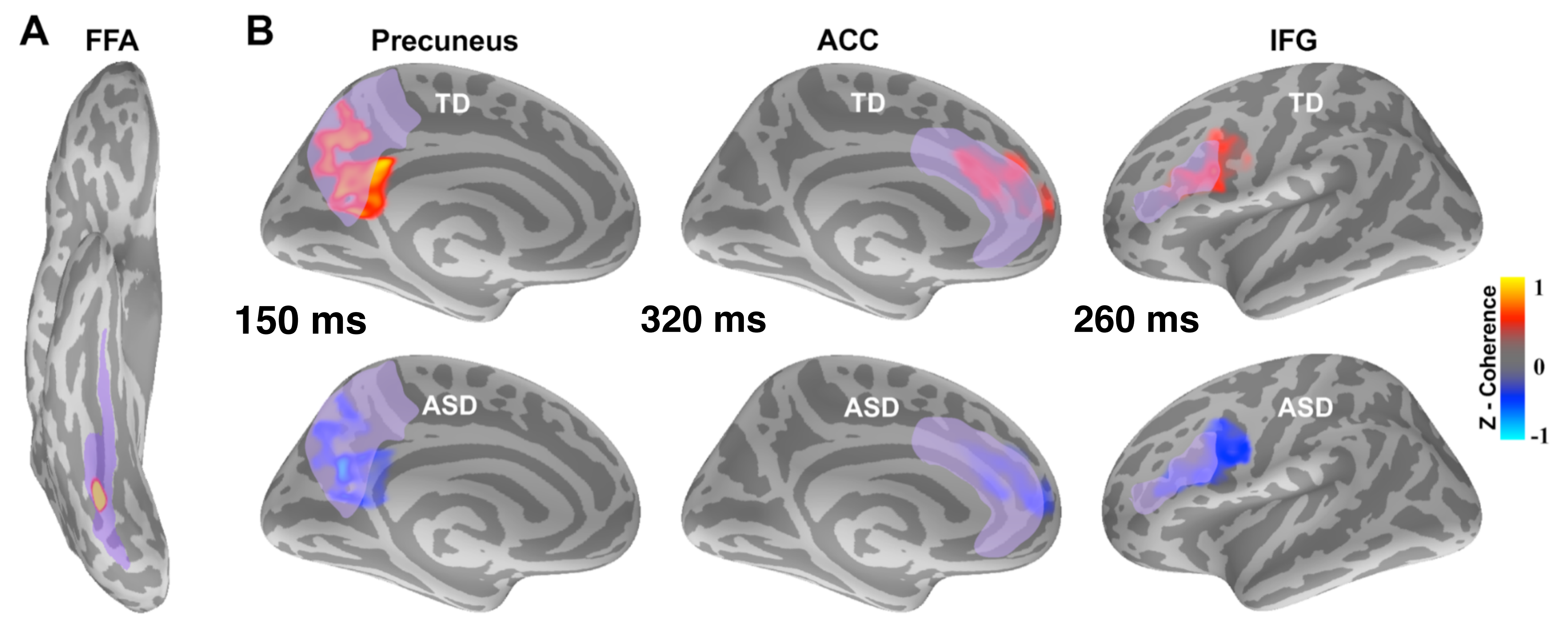
Ahveninen J, Huang S, Ahlfors SP, Hämäläinen M, Rossi S, Sams M, Jääskeläinen IP. Neuroimage, 2016. 124: p. 858-868. PMC4651767

Different Frequency Bands in Connectivity



Robert Oostenveld

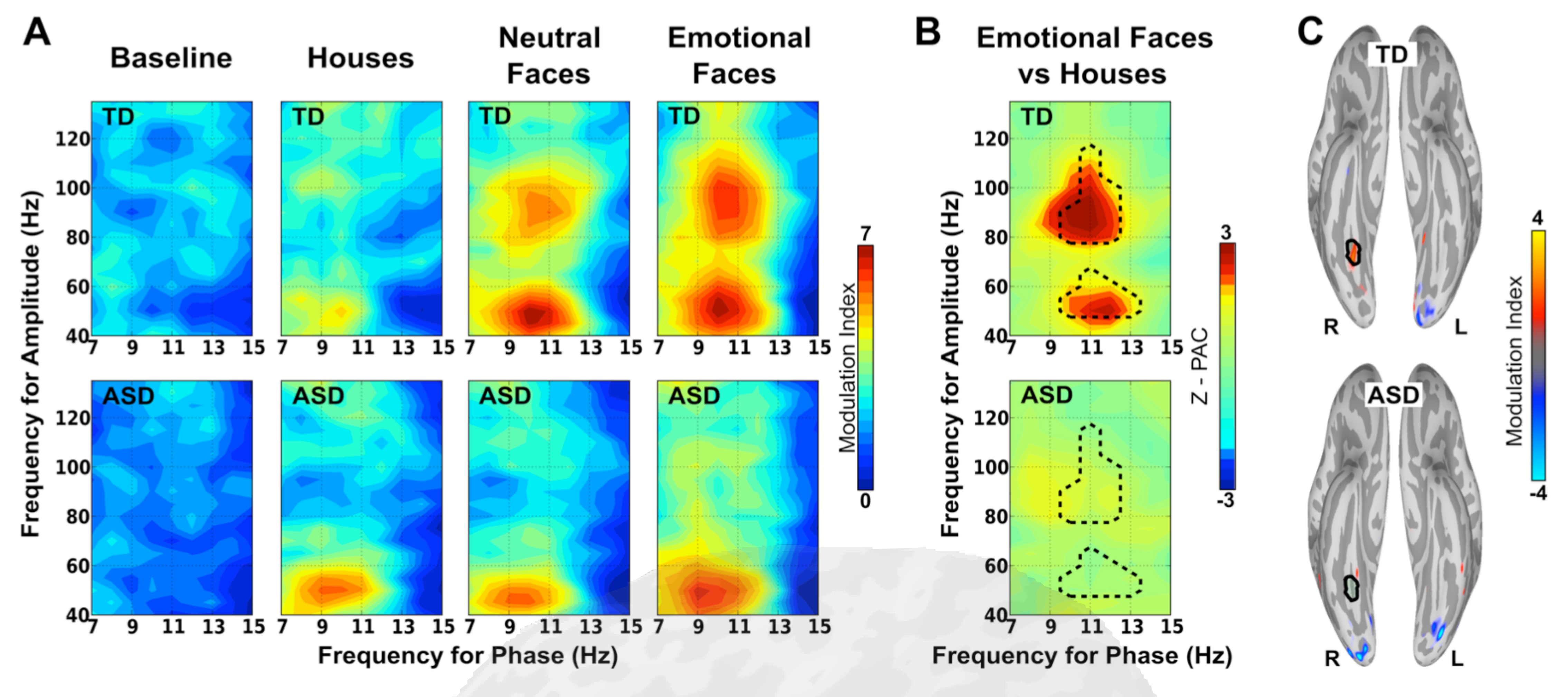
Spatially and Temporally Specific Differences in Long-Range Connectivity



- FFA seed, normalized (Z) coherence
- Alpha band (8 - 12 Hz)
- Emotional faces > houses
- Houses > emotional faces

Khan et al., PNAS, 2013

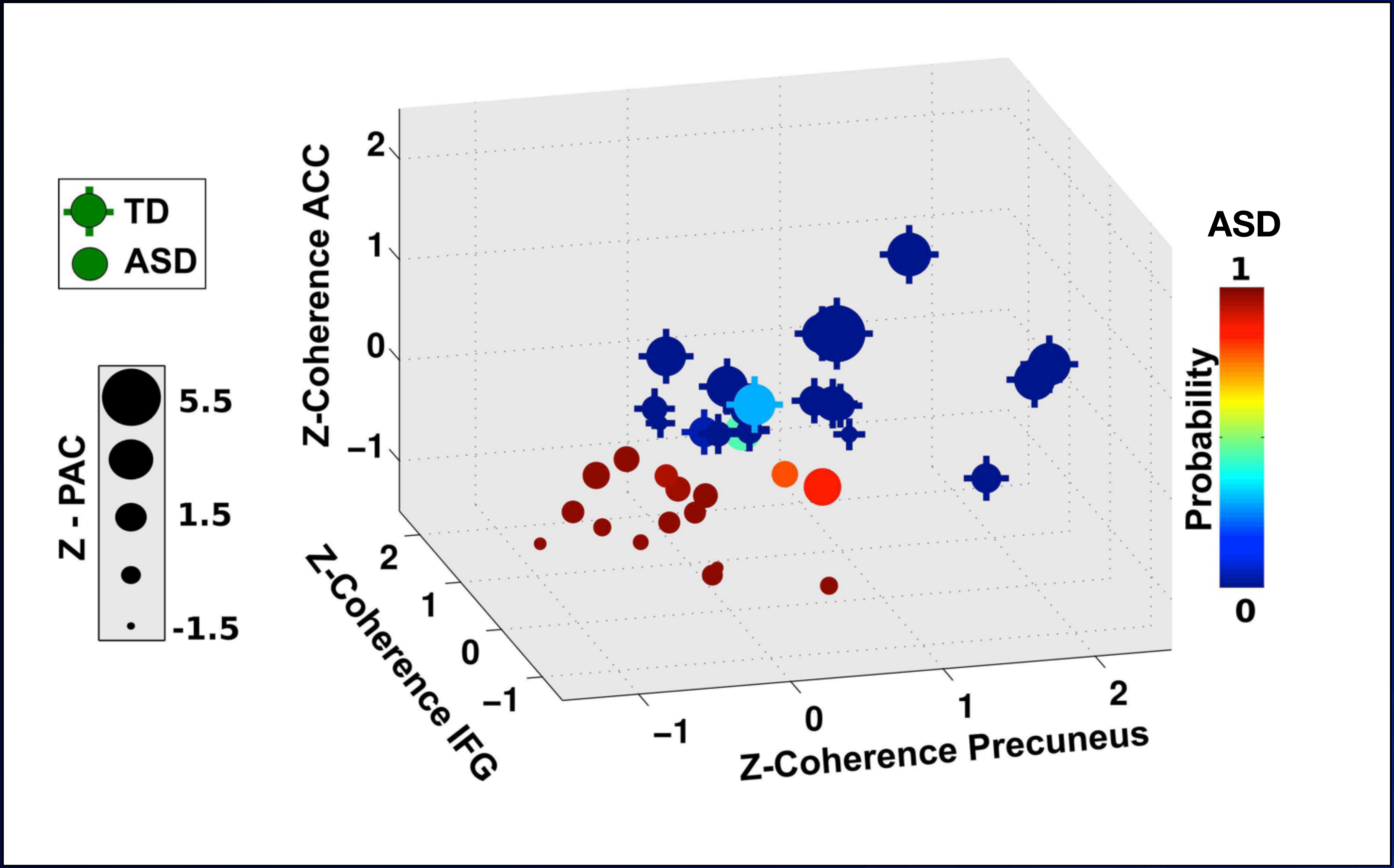
Local Connectivity Different in FFA only



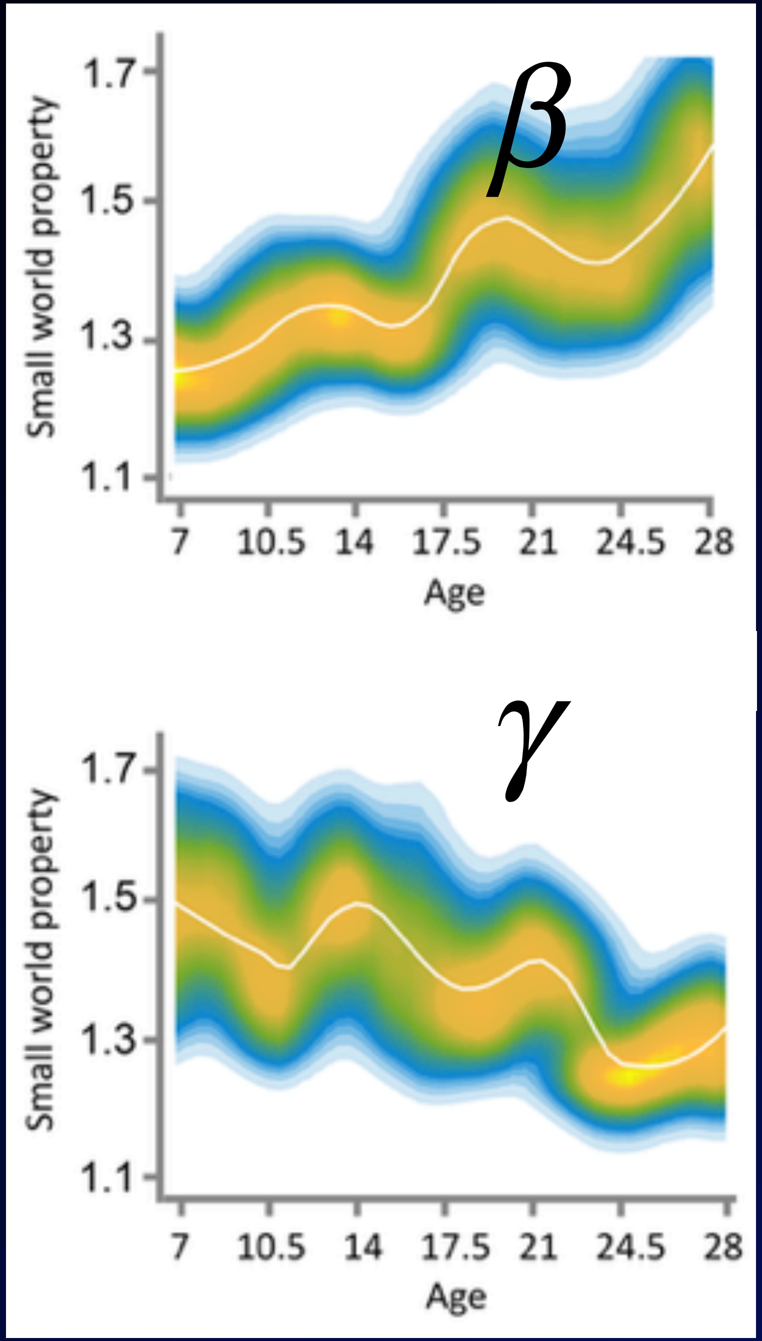
- Phase-Amplitude Coupling differences between emotional faces and houses only in controls
- Alpha band (8 - 12 Hz) phase and gamma band amplitude coupled

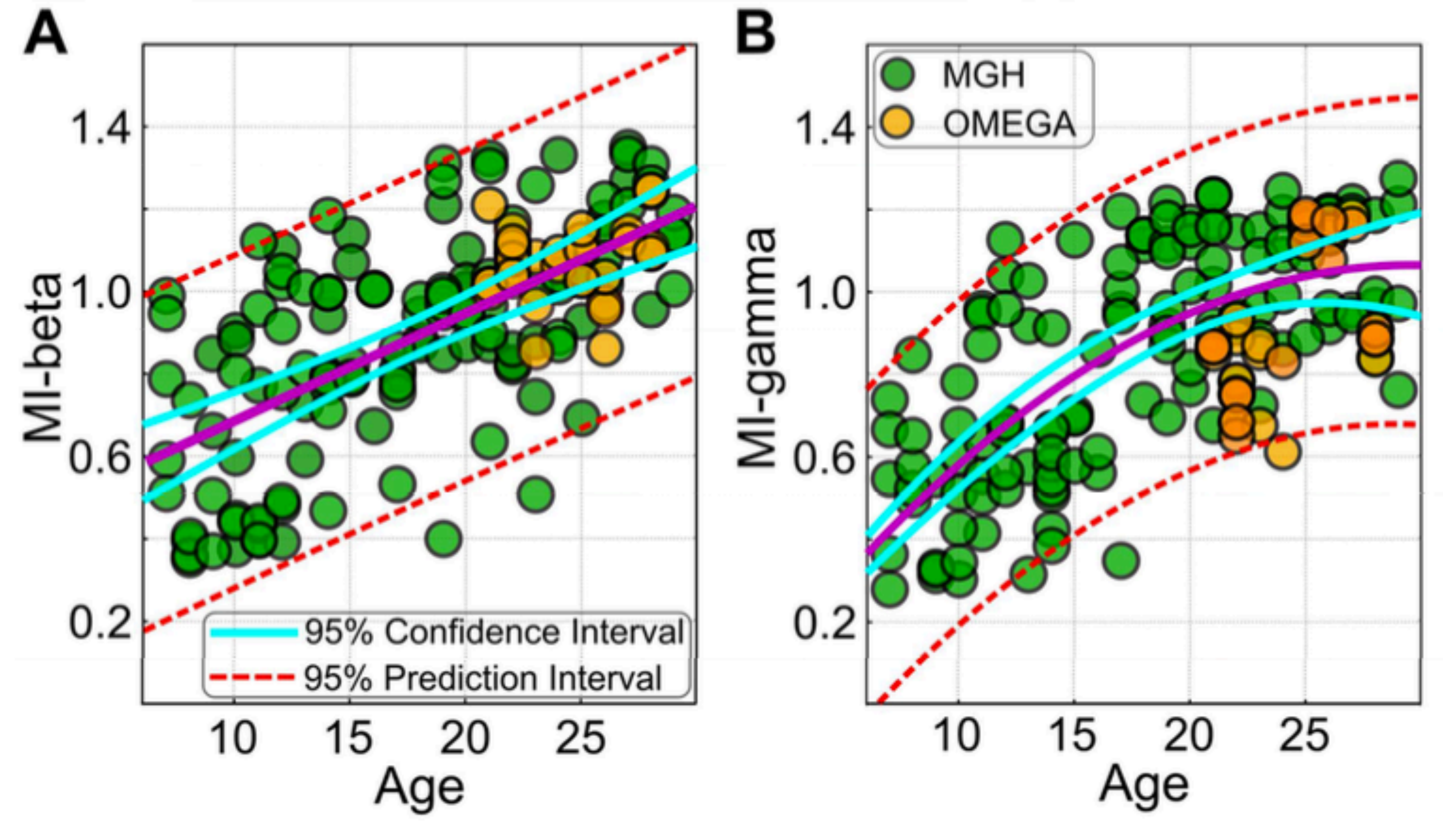
Khan et al., PNAS, 2013

The Signatures Correlate with Behavior



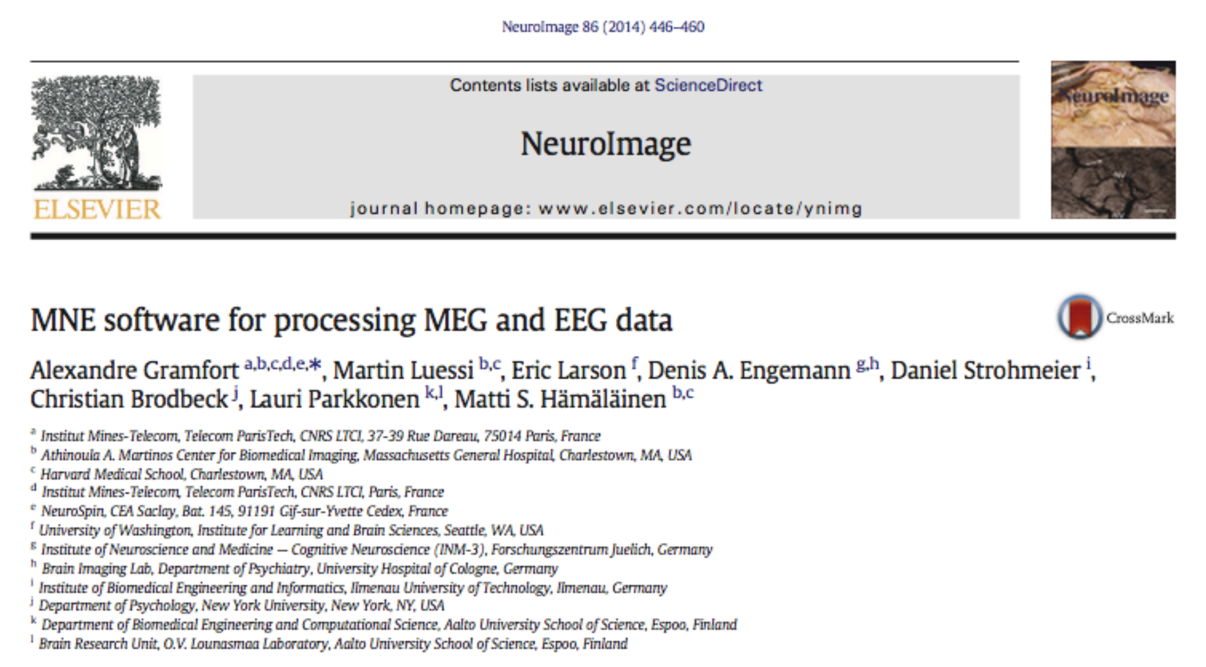
Cortical Beta and Gamma Rhythm Resting-State Networks Follow Distinct Maturation Trajectories





Khan et al., Neuroimage, 2018

Academic Software



NeuroImage 86 (2014) 446–460

Contents lists available at ScienceDirect

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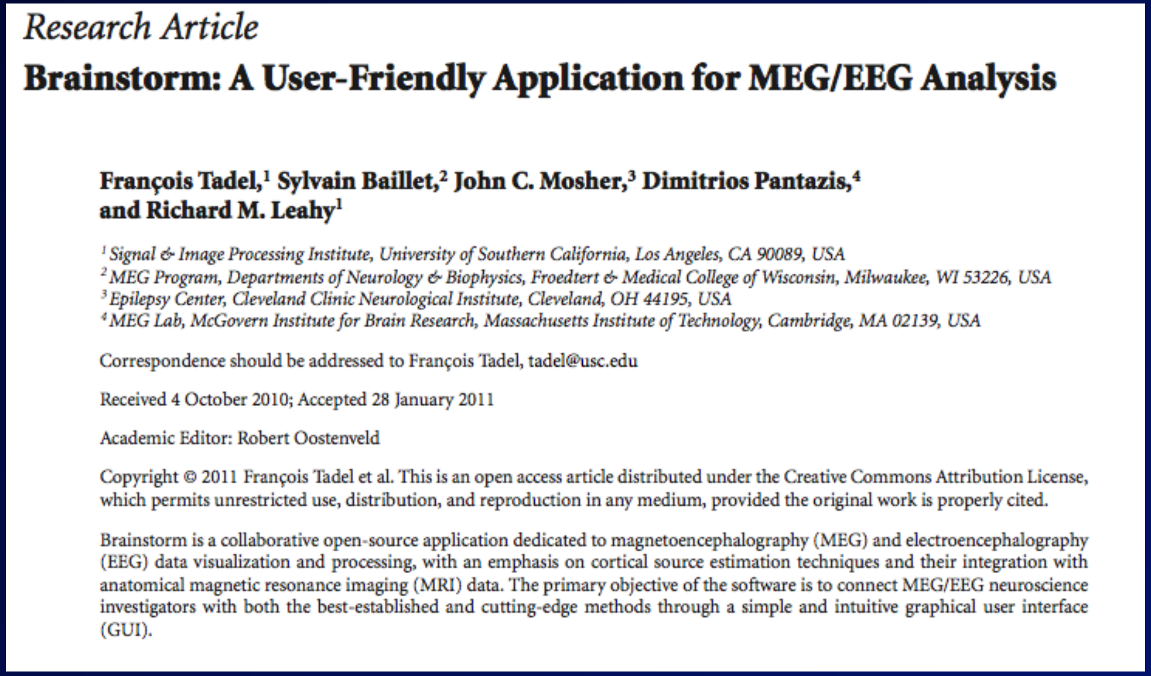
journal homepage: www.elsevier.com/locate/ynimg

MNE software for processing MEG and EEG data

Alexandre Gramfort [a,b,c,d,e,*], Martin Luessi [b,c], Eric Larson [f], Denis A. Engemann [g,h], Daniel Strohmeier [i], Christian Brodbeck [j], Lauri Parkkonen [k,l], Matti S. Hämäläinen [b,c]

[a] *Institut Mines-Telecom, Telecom ParisTech, CNRS LTCI, 37-39 Rue Dareau, 75014 Paris, France*
[b] *Athinoula A. Martinos Center for Biomedical Imaging, Massachusetts General Hospital, Charlestown, MA, USA*
[c] *Harvard Medical School, Charlestown, MA, USA*
[d] *Institut Mines-Telecom, Telecom ParisTech, CNRS LTCI, Paris, France*
[e] *NeuroSpin, CEA Saclay, Bat. 145, 91191 Gif-sur-Yvette Cedex, France*
[f] *University of Washington, Institute for Learning and Brain Sciences, Seattle, WA, USA*
[g] *Institute of Neuroscience and Medicine — Cognitive Neuroscience (INM-3), Forschungszentrum Juelich, Germany*
[h] *Brain Imaging Lab, Department of Psychiatry, University Hospital of Cologne, Germany*
[i] *Institute of Biomedical Engineering and Informatics, Ilmenau University of Technology, Ilmenau, Germany*
[j] *Department of Psychology, New York University, New York, NY, USA*
[k] *Department of Biomedical Engineering and Computational Science, Aalto University School of Science, Espoo, Finland*
[l] *Brain Research Unit, O.V. Lounasmaa Laboratory, Aalto University School of Science, Espoo, Finland*



Research Article

Brainstorm: A User-Friendly Application for MEG/EEG Analysis

François Tadel,[1] Sylvain Baillet,[2] John C. Mosher,[3] Dimitrios Pantazis,[4] and Richard M. Leahy[1]

[1] *Signal & Image Processing Institute, University of Southern California, Los Angeles, CA 90089, USA*
[2] *MEG Program, Departments of Neurology & Biophysics, Froedtert & Medical College of Wisconsin, Milwaukee, WI 53226, USA*
[3] *Epilepsy Center, Cleveland Clinic Neurological Institute, Cleveland, OH 44195, USA*
[4] *MEG Lab, McGovern Institute for Brain Research, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

Correspondence should be addressed to François Tadel, tadel@usc.edu

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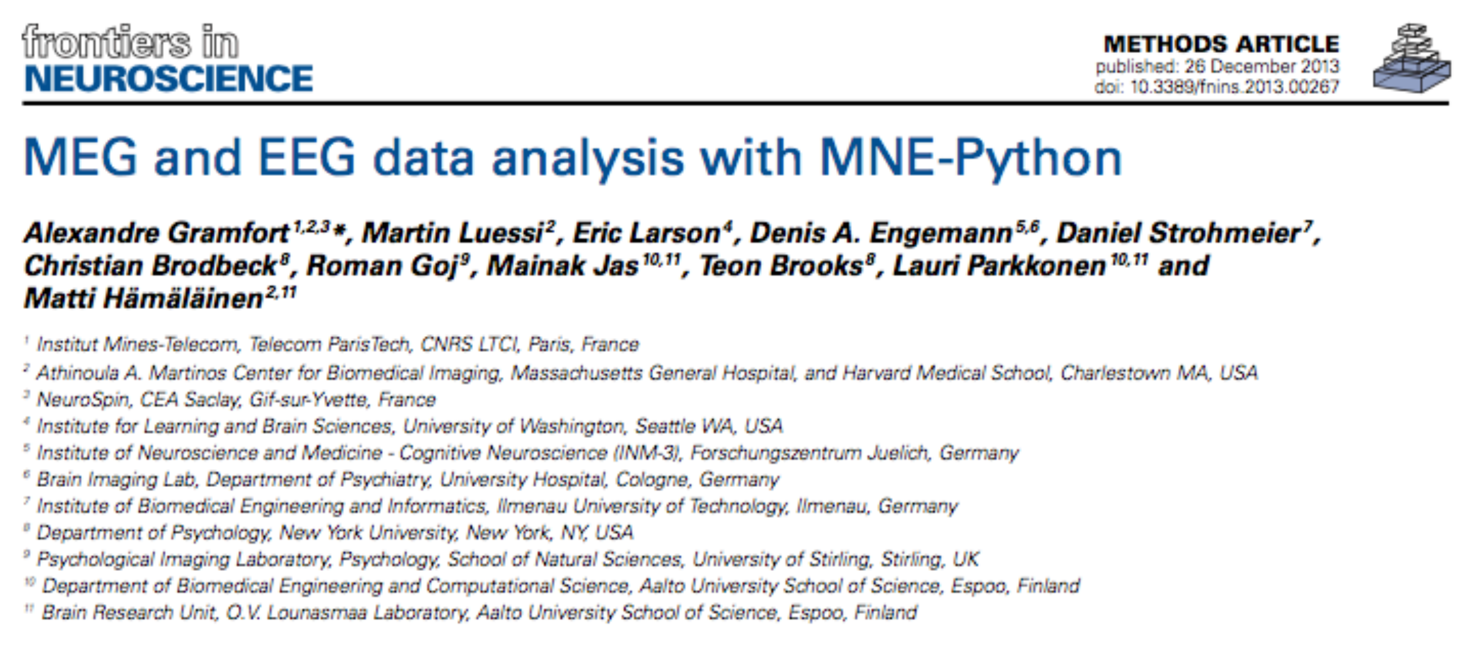
Brainstorm is a collaborative open-source application dedicated to magnetoencephalography (MEG) and electroencephalography (EEG) data visualization and processing, with an emphasis on cortical source estimation techniques and their integration with anatomical magnetic resonance imaging (MRI) data. The primary objective of the software is to connect MEG/EEG neuroscience investigators with both the best-established and cutting-edge methods through a simple and intuitive graphical user interface (GUI).



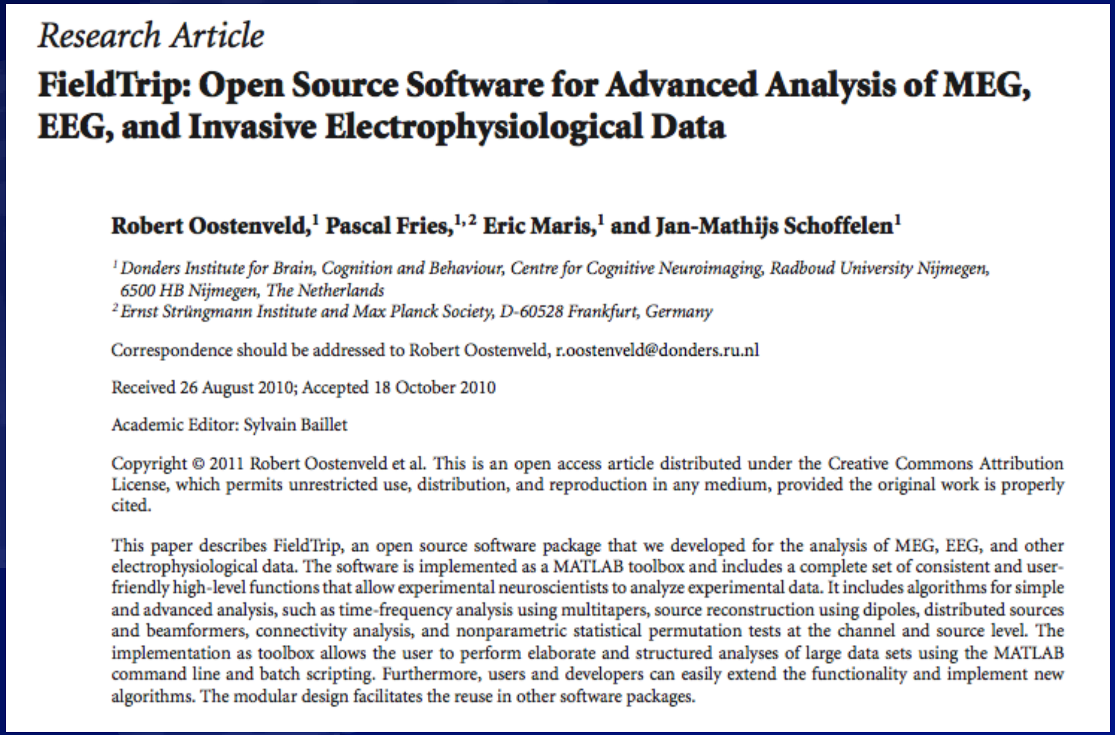
frontiers in
NEUROSCIENCE

METHODS ARTICLE
published: 26 December 2013
doi: 10.3389/fnins.2013.00267

MEG and EEG data analysis with MNE-Python

Alexandre Gramfort[1,2,3]*, Martin Luessi[2], Eric Larson[4], Denis A. Engemann[5,6], Daniel Strohmeier[7], Christian Brodbeck[8], Roman Goj[9], Mainak Jas[10,11], Teon Brooks[8], Lauri Parkkonen[10,11] and Matti Hämäläinen[2,11]

[1] *Institut Mines-Telecom, Telecom ParisTech, CNRS LTCI, Paris, France*
[2] *Athinoula A. Martinos Center for Biomedical Imaging, Massachusetts General Hospital, and Harvard Medical School, Charlestown MA, USA*
[3] *NeuroSpin, CEA Saclay, Gif-sur-Yvette, France*
[4] *Institute for Learning and Brain Sciences, University of Washington, Seattle WA, USA*
[5] *Institute of Neuroscience and Medicine - Cognitive Neuroscience (INM-3), Forschungszentrum Juelich, Germany*
[6] *Brain Imaging Lab, Department of Psychiatry, University Hospital, Cologne, Germany*
[7] *Institute of Biomedical Engineering and Informatics, Ilmenau University of Technology, Ilmenau, Germany*
[8] *Department of Psychology, New York University, New York, NY, USA*
[9] *Psychological Imaging Laboratory, Psychology, School of Natural Sciences, University of Stirling, Stirling, UK*
[10] *Department of Biomedical Engineering and Computational Science, Aalto University School of Science, Espoo, Finland*
[11] *Brain Research Unit, O.V. Lounasmaa Laboratory, Aalto University School of Science, Espoo, Finland*



Research Article

FieldTrip: Open Source Software for Advanced Analysis of MEG, EEG, and Invasive Electrophysiological Data

Robert Oostenveld,[1] Pascal Fries,[1,2] Eric Maris,[1] and Jan-Mathijs Schoffelen[1]

[1] *Donders Institute for Brain, Cognition and Behaviour, Centre for Cognitive Neuroimaging, Radboud University Nijmegen, 6500 HB Nijmegen, The Netherlands*
[2] *Ernst Strüngmann Institute and Max Planck Society, D-60528 Frankfurt, Germany*

Correspondence should be addressed to Robert Oostenveld, r.oostenveld@donders.ru.nl

Received 26 August 2010; Accepted 18 October 2010

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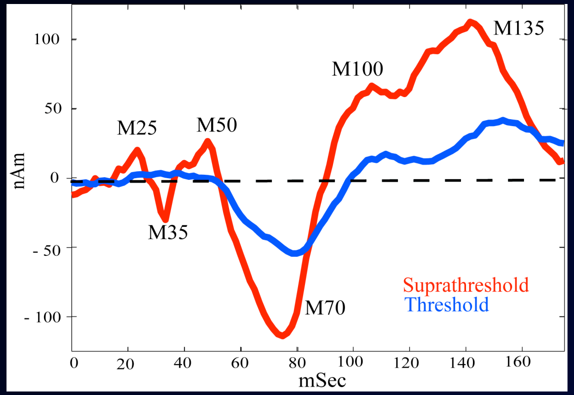
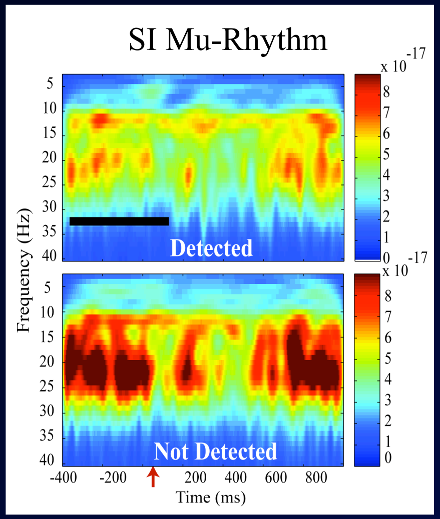
This paper describes FieldTrip, an open source software package that we developed for the analysis of MEG, EEG, and other electrophysiological data. The software is implemented as a MATLAB toolbox and includes a complete set of consistent and user-friendly high-level functions that allow experimental neuroscientists to analyze experimental data. It includes algorithms for simple and advanced analysis, such as time-frequency analysis using multitapers, source reconstruction using dipoles, distributed sources and beamformers, connectivity analysis, and nonparametric statistical permutation tests at the channel and source level. The implementation as toolbox allows the user to perform elaborate and structured analyses of large data sets using the MATLAB command line and batch scripting. Furthermore, users and developers can easily extend the functionality and implement new algorithms. The modular design facilitates the reuse in other software packages.

Bridging Microscopic and Macroscopic Neurophysiology

MEG Source Estimates

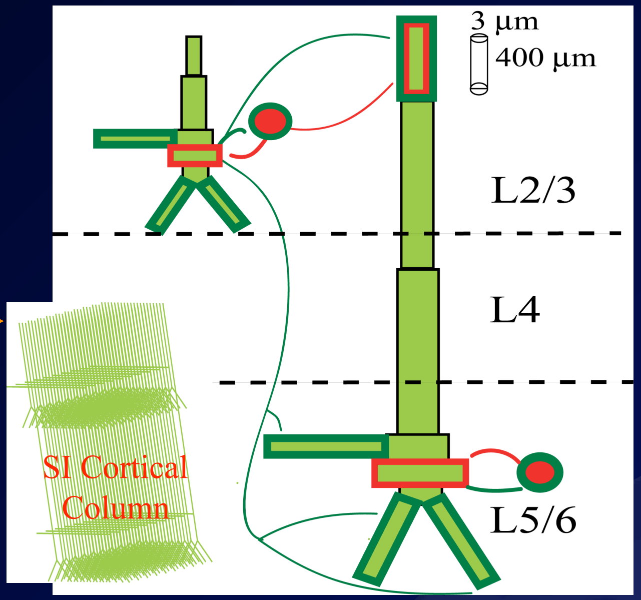




Example subject. Avg n=100 trials

Steven Stufflebeam
Matti Hämäläinen

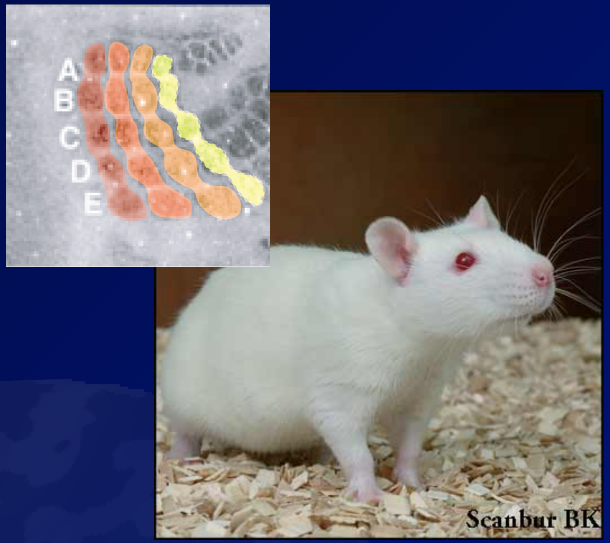
Computational Neural Modeling



Predicted cellular level neural dynamics

Stephanie Jones

Animal Electrophysiology



Cellular level details of neural dynamics

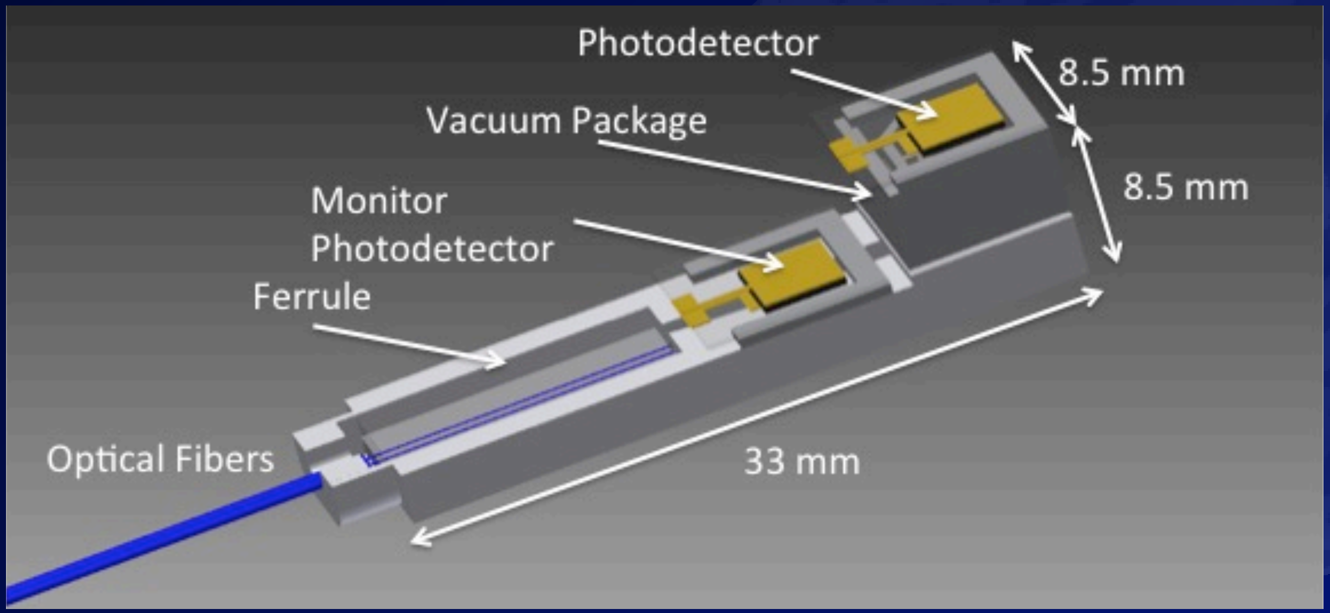
Chris Moore

Neural mechanisms of transient neocortical beta rhythms: Converging evidence from humans, computational modeling, monkeys, and mice, Sherman et al., PNAS, 2016

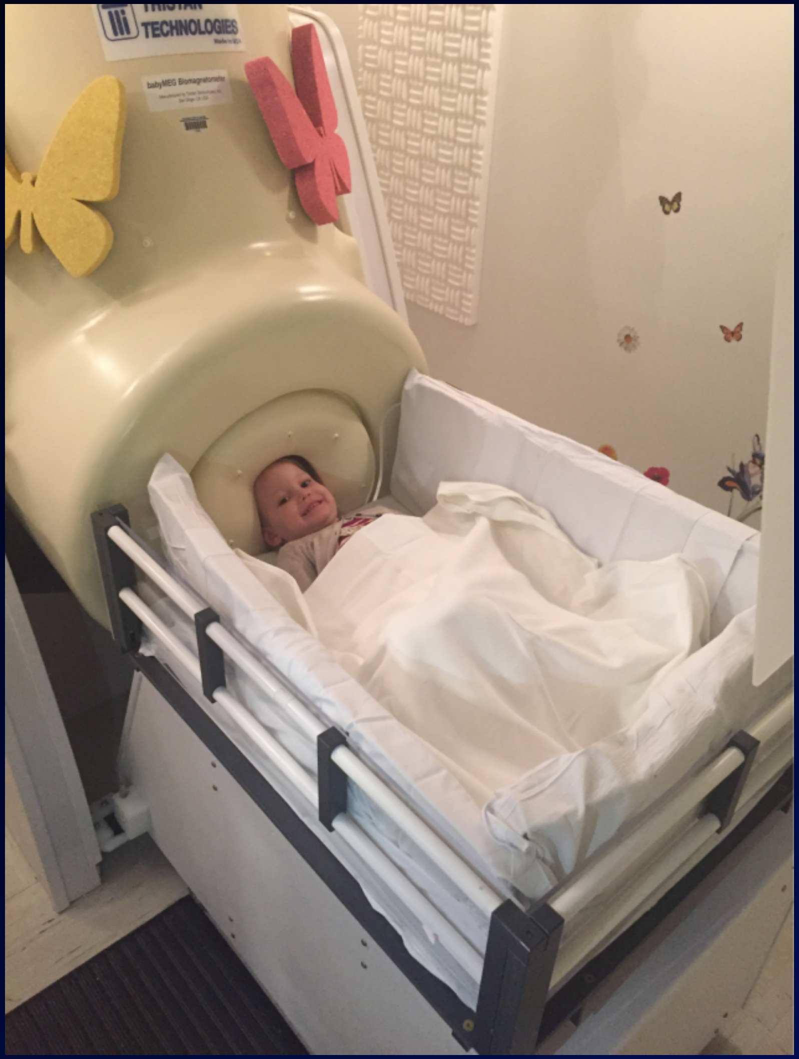
MNE-Neuron Software: NIH R01EB02288

New Sensor Technologies

- Improvements to conventional LowTc SQUID technology
- HighTc SQUIDs
  - High sensitivity finally reached
  - Still needs cryogens
- Optically Pumped Magnetometers (OPMs)



Whole-Head MEG for Infants: the BabyMEG



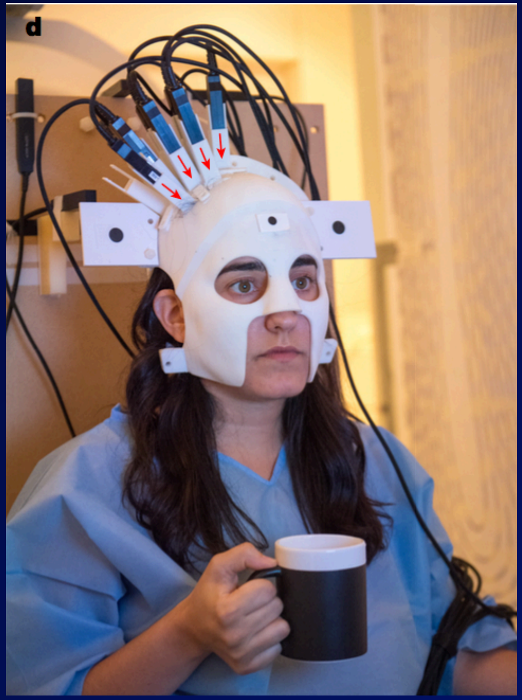
- First whole-head infant MEG system with optimal sensor density
- Low-Tc SQUID system
- 275 primary magnetometers
- 35 three-axis compensation magnetometers
- Distance from sensors to room temperature (~ 6 mm)
- Cryocooler for closed-circuit He system

- Ellen Grant & Yoshio Okada (BCH), Matti Hämäläinen (MGH)
- Supported by NSF

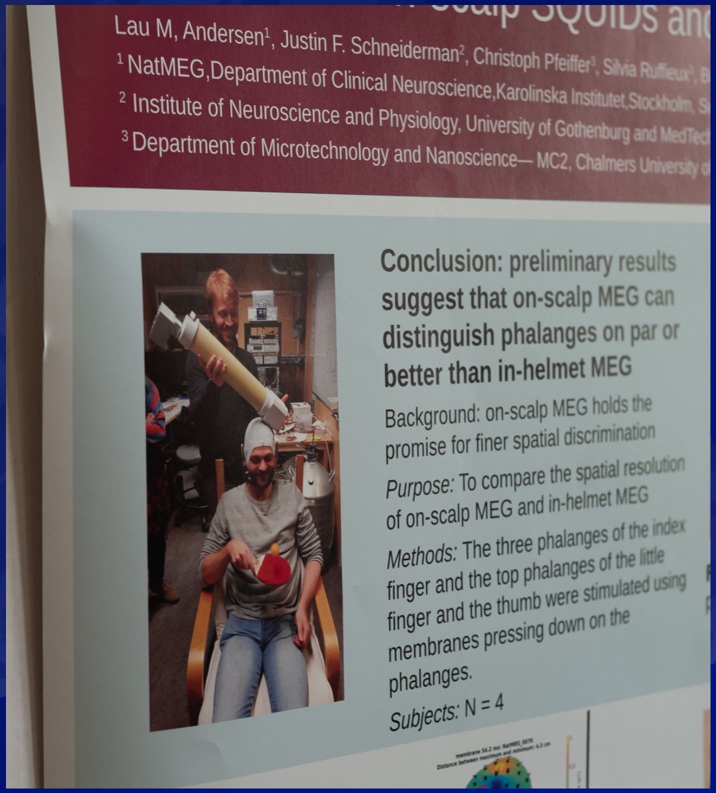
Okada et al., Rev. Sci. Instrum., 2016

New Possibilities with New Sensors

- On-scalp MEG
- Adaptable MEG
- Simultaneous MEG from several subjects?
- MEG/TMS



Boto et al., Nature 2018



Lau M, Andersen[1], Justin F. Schneiderman[2], Christoph Pfeiffer[3], Silvia Ruffieux[3],
[1] NatMEG,Department of Clinical Neuroscience,Karolinska Institutet,Stockholm,
[2] Institute of Neuroscience and Physiology, University of Gothenburg and
[3] Department of Microtechnology and Nanoscience— MC2, Chalmers University

Conclusion: preliminary results suggest that on-scalp MEG can distinguish phalanges on par or better than in-helmet MEG

Background: on-scalp MEG holds the promise for finer spatial discrimination

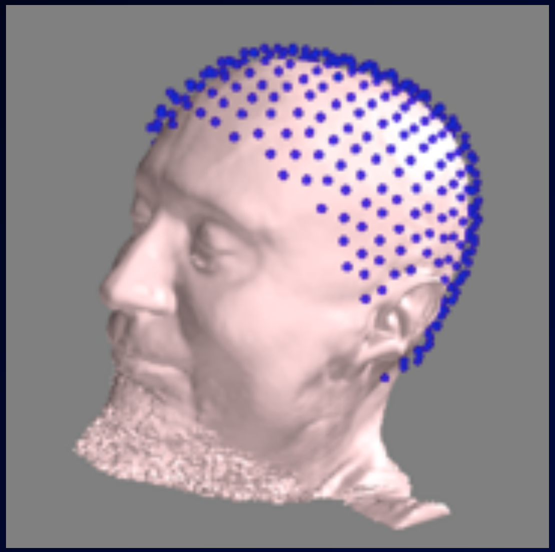
Purpose: To compare the spatial resolution of on-scalp MEG and in-helmet MEG

Methods: The three phalanges of the index finger and the top phalanges of the little finger and the thumb were stimulated using membranes pressing down on the phalanges.

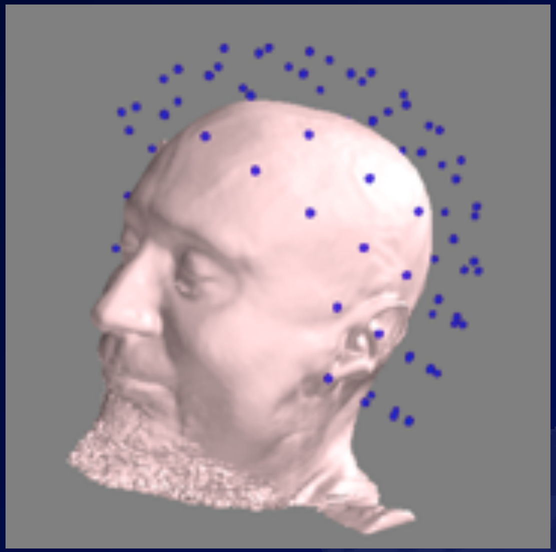
Subjects: N = 4

Andersen et al., 2018

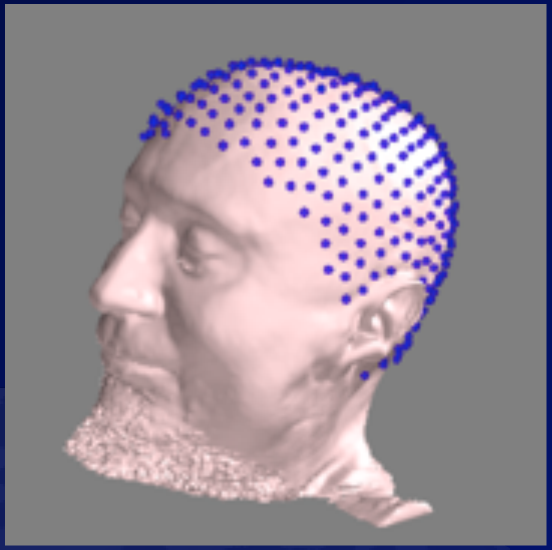
Comparison of Sensor Arrays



500-channel On-scalp MEG



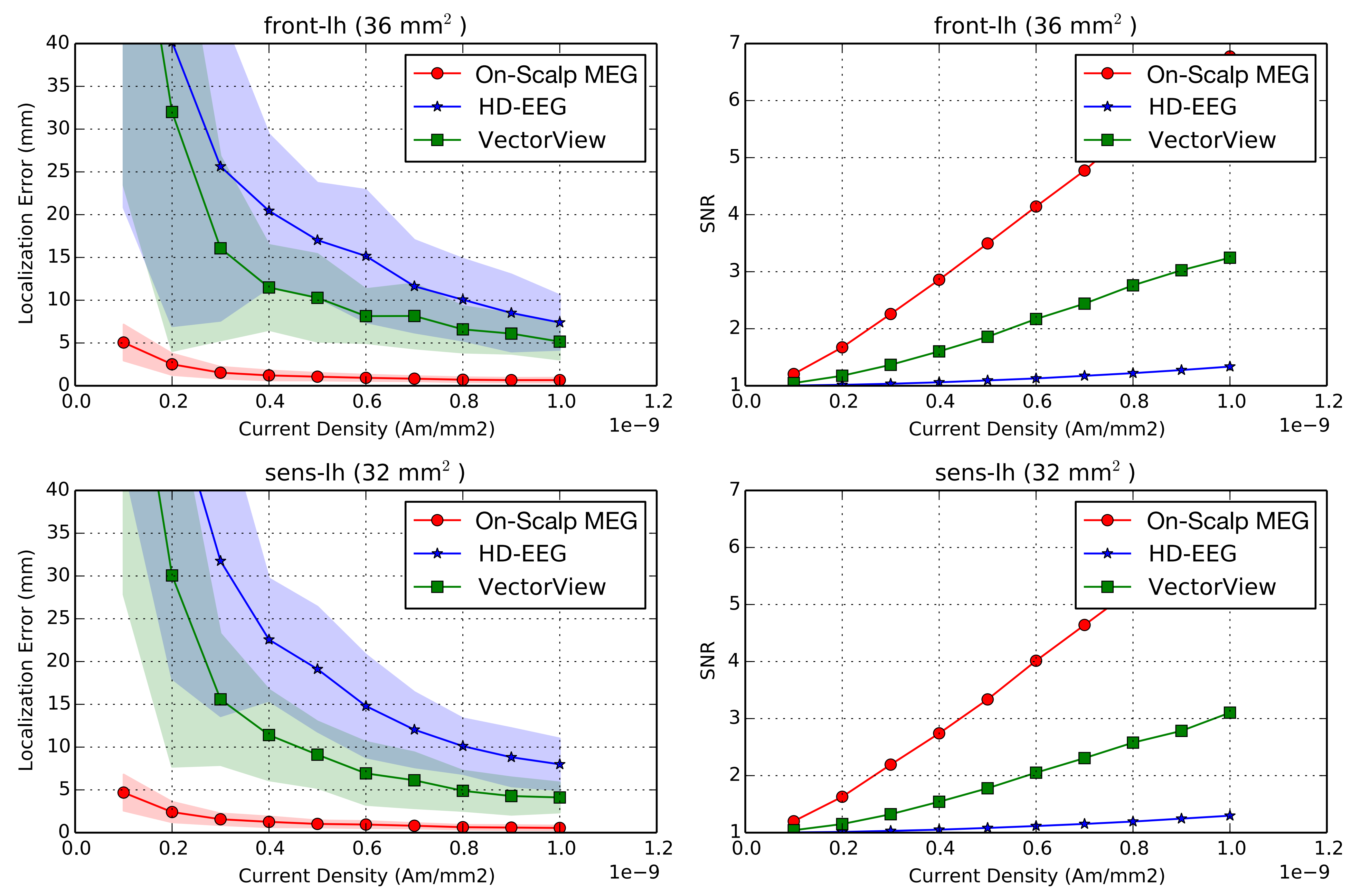
VectorView



500-channel EEG

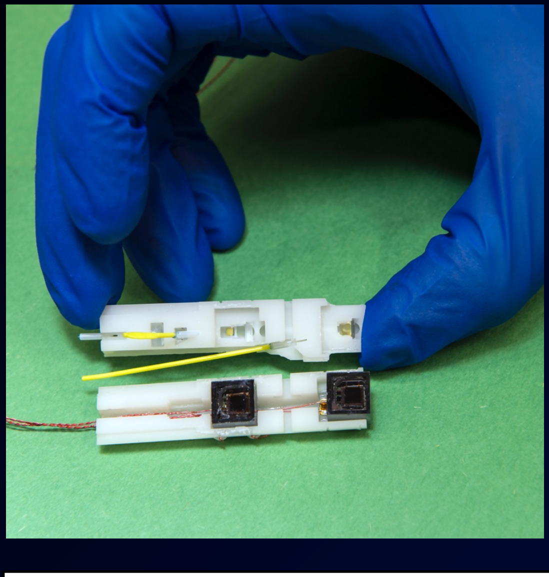
Luessi et al., 2014

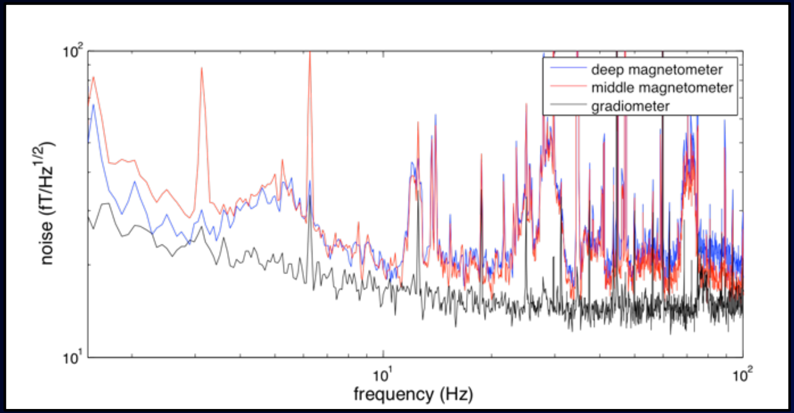
Localization Errors for Cortical Sources

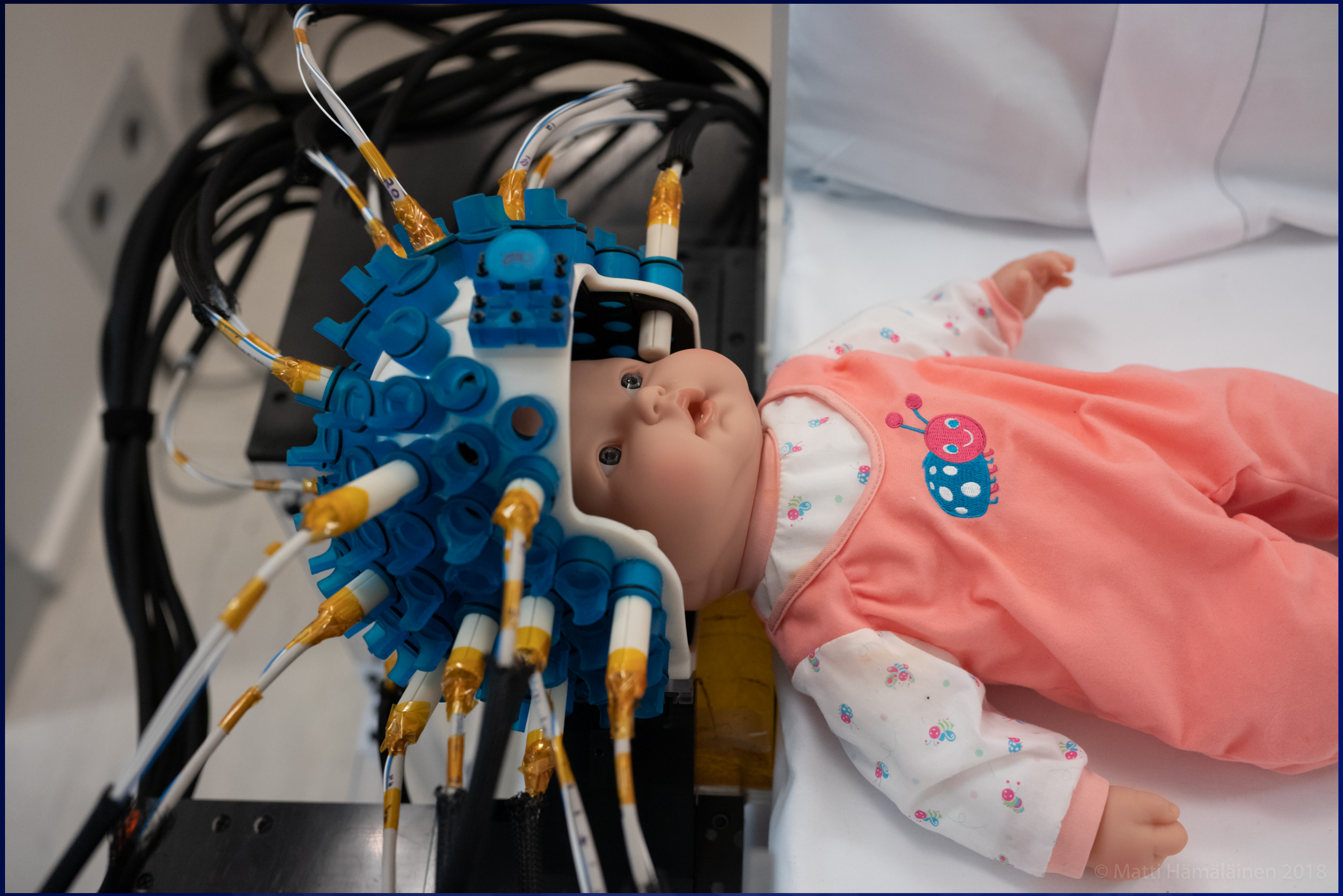


Luessi et al., 2014

Lifespan MEG: Premature babies to elderly







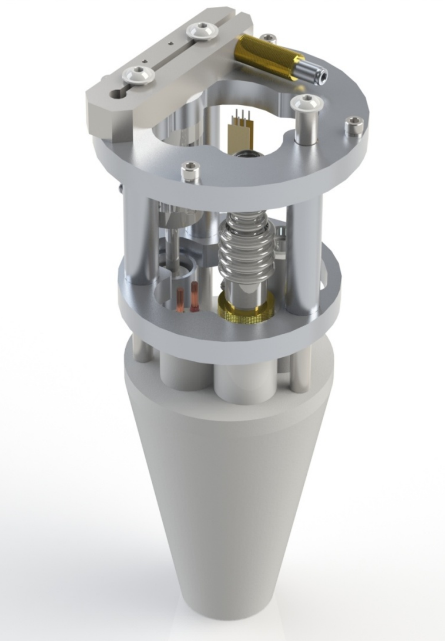
Under construction

- 64-channel flexible, conformal MEG (128 slots)
- Optically pumped atomic magnetometers

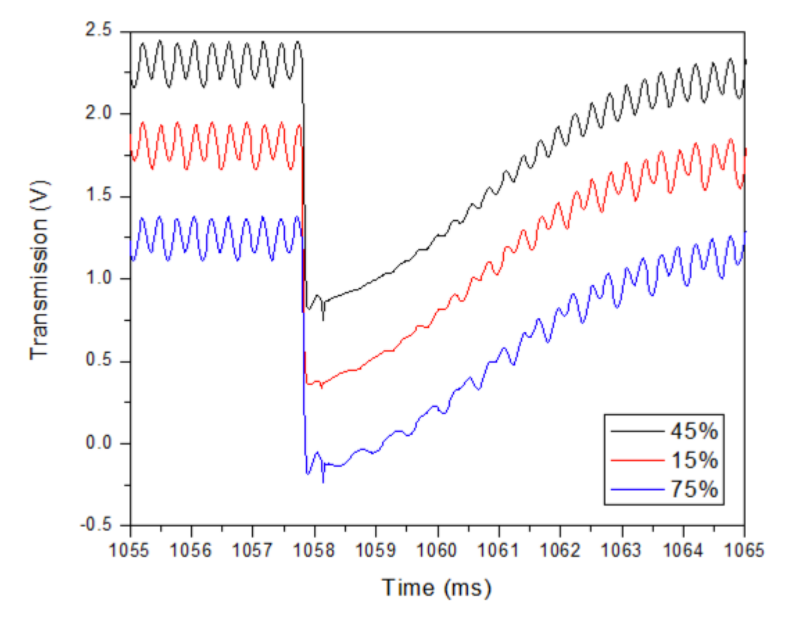
Svenja Knappe (PI): Conformal Pediatric Whole-Head MEG System with Optically-Pumped Magnetometers (5R01EB019440-03)

Integrated Multichannel TMS-MEG

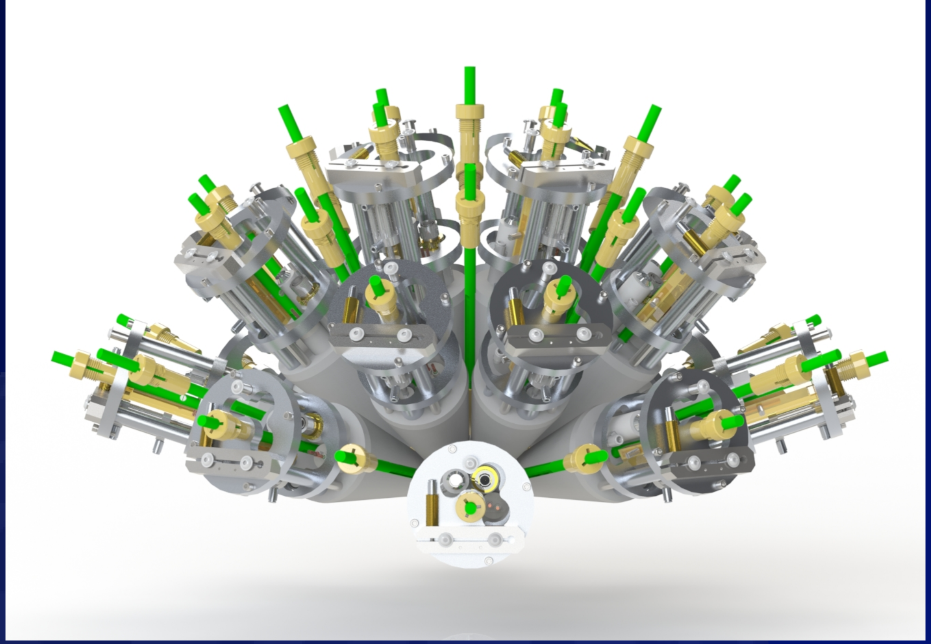
- 16 liquid-nitrogen cooled TMS probes
- 25 atomic magnetometers for recording MEG



Cryo-TMS probe



4 ms recovery of AM
sensors after a TMS pulse

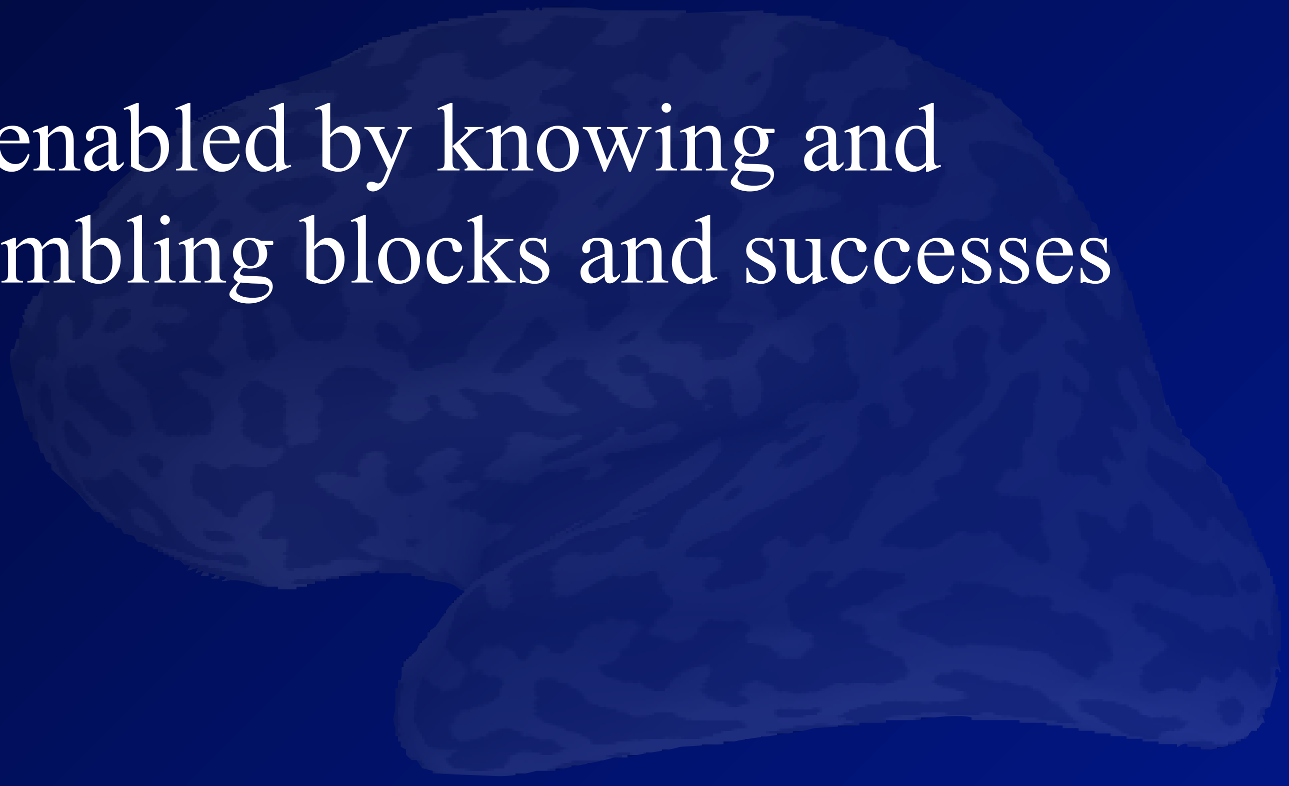


TMS-MEG array

Douglas Paulson (PI): Non-Invasive Integrated System for Brain Stimulation and Magnetocorticography (5R44NS090894-03)

Summary

- The multidisciplinary approach has been the key to advances in MEG instruments, methods, and applications
- The advances in devices will inspire and necessitate advances in signal processing and data analysis methods
- New breakthroughs are enabled by knowing and appreciating the past stumbling blocks and successes



Essentials

Best people with different backgrounds work together daily:

“Both information and gossip travel at the speed of light but information travels only 10 meters”

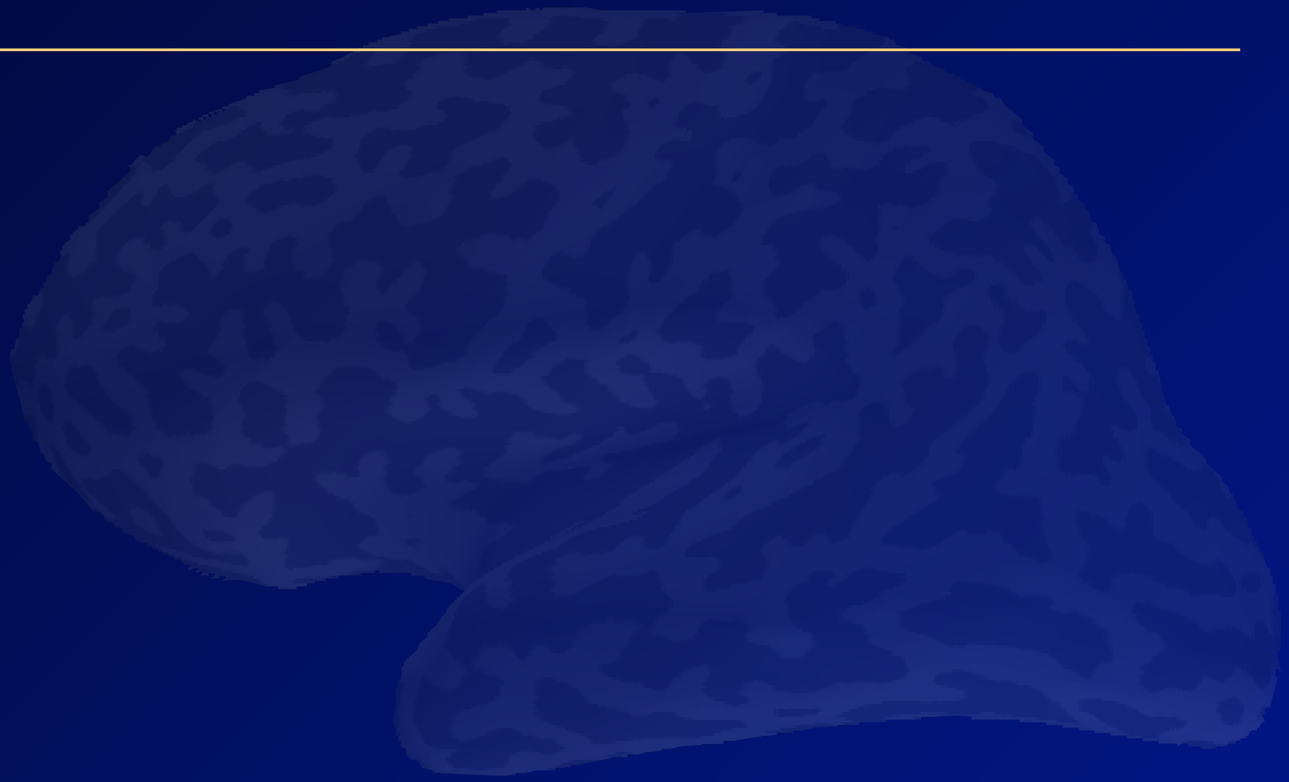
“People are very stubborn there, very stubborn.”

Molotov about Finland, 1974

Effect of sustained exposure to MEG

Ole Jensen (20 y) Sylvain Baillet (23 y) Matti Hämäläinen (37 y)

“Sometimes statistics are really not necessary:
three subjects is enough.”



- NIH R01EB0009048
- NIH P41EB015896
- NIH U01EB023820
- NIH R01EB022889
- NIH R01MH106174
- NSF 0958669
- NSF 0959294

Thank you!